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Research Article

A baseline assessment of anthropogenic macrolitter on dunes along the Bulgarian Black Sea Coast using visual census and Unmanned Aerial Systems

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Abstract

Beach-dune systems are among the most dynamic and sensitive elements of coastal ecosystems in the world. They represent an intersection between human activities, flora, fauna and economic interests in tourism. The Bulgarian Black Sea shoreline spans 518.7 km and comprises 131 km (25%) of the depositional coast, including beaches and 46 dune systems. Over the past three decades, heavy anthropogenic impacts have been observed, significantly altering the cleanliness of the beach-dune systems along the Bulgarian Black Sea Coast (BBSC). The research initially began as an initial assessment of macrolitter on dunes (MLD) using Unmanned Aerial Systems (UAS). However, due to concerning data obtained in the first year, it transitioned into a mid-term monitoring program conducted between 2018 and 2022. The baseline assessment is based on a visual census, UAS mapping and manual image screening procedure in a GIS environment for litter mapping in 40 areas of litter monitoring (ALMs) along the Bulgarian Coast. Throughout the five-year monitoring period, the most abundant type of MLD was "Artificial polymer materials," accounting for 83.4% of the total number, followed by "Paper/Cardboard" (6.2%), "Glass/Ceramics" (2.8%), "Metal" (2.8%), "Processed/Worked wood" (1.83%), "Rubber" (1.29%), and "Cloth/Textile" (1.17%). Generally, 95% of the total litter amount was assessed from Land-based sources and 5% from Sea-based sources. The COVID-19 pandemic indirectly affected the cleanliness of the Bulgarian dunes due to restrictions on foreign travel, which increased the domestic tourist pressure on the Bulgarian beaches, resulting in a more significant amount of waste accumulating on the beaches and dunes. The abundance experienced an increase of 39% between 2018 and 2021. A similar upward trend (+41%) was observed in the density of macrolitter on the dunes. Based on visual census data, the average density was estimated to be 0.54 ± 0.35 items/m^2. The spatial distribution of MLD is a complex combination of anthropogenic impact and wind processes that affect various eco-geomorphological elements of the beach-dune system. The embryonic dunes retained only 16% of the total items (Dav: 0.32 ± 0.12 items/m^2). The highest litter density was registered on the foredunes (Dav: 0.71 ± 0.21 items/m^2; 28% of total items). The backdunes contained the highest litter abundance, accounting for 55% in larger areas (Dav:0.59 items/m^2). Density litter maps established that dune vegetation acted as a natural trap, retaining 40% more macrolitter compared to areas without dune plants. A Clean Dune Index (CDI) was developed to evaluate the cleanliness of Bulgarian dunes. Based on aggregated CDI data for 2018–2022, the cleanliness of the dunes along the Bulgarian Coast was categorised as "moderate" (CDIav:10.89). Dune systems near the most visited resorts were

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classified as "extremely dirty", with the highest CDI values recorded at Kavatsite (27.22), Nessebar – South (25.01), Bolata (24.69), Asparuhovo - Varna (24.33) and Slanchev bryag (24.09). On the other hand, the dune systems at Ropotamo and Lipite were rated with the lowest CDI – 0.95 and 1.2. Dunes are sensitive habitats and require minimal anthropogenic impact, which requires the intensification of the use of high-resolution remote sensing methods for litter mapping. The quality of the presented data and the results obtained outline drones as a future primary tool for beach and dune surveys.

Key words: Abundance, baseline assessment, Bulgarian Black Sea Coast, dune pollution, macrolitter, monitoring, unmanned aerial systems (UAS)

Introduction

World Ocean and marine litter

Sandy beaches and coastal dunes are widespread landforms along coastlines worldwide (Martínez et al. 2008; Bird 2011; Luijendijk et al. 2018, etc.) and hold significant geological, biological, and ecological importance (Hesp 2002; Masselink et al. 2011; Jackson et al. 2019, etc.). Currently, the impact of anthropogenic marine litter (AML) on these landforms and the marine environment is recognised as a threat to marine wildlife under Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy, MSFD (European Commission 2008) and international provisions such as the United Nations Sustainable Development Goal 14 (UN RES/70/1 2015). Recent global efforts have led to the United Nations signing the first resolution specifically targeting plastic pollution. This resolution aims to guide the development of a legally binding treaty by 2024 (UNEP 2022).

In recent decades, there has been a noticeable increase in the accumulation of AML, especially plastic debris, in various environmental compartments spanning from the north to the south pole (Galgani 2015; Galgani et al. 2015; Monteiro et al. 2018, etc.). Marine litter (ML) consists of plastic, glass/ceramic, metal, wood/paper, textiles, and rubber (Galgani et al. 2013a), with plastic being the predominant type, comprising 60–80% of all litter (Barboza et al. 2019). Anthropogenic debris has become a significant pollutant in marine, coastal and terrestrial environments, posing risks to species' survival and potential adverse effects on human health (Galgani et al. 2013b;Wright et al. 2013; Panti et al. 2019). The most significant threats to human health and implications for environmental and ecological well-being are associated with anthropogenic ML (Leal Filho et al. 2019). Negative impacts of microplastic pollution on the marine environment include entanglement (Gregory 2009; Thiel et al. 2018), ingestion (Savoca et al. 2021), bioaccumulation of persistent organic and inorganic pollutants (Teuten et al. 2009; Ranjani et al. 2022) and a transfer of non-native species through hitchhiking (Al-Khayat et al. 2021). Furthermore, ML has detrimental effects on the economies of coastal countries (McIlgorm et al. 2011; Brouwer et al. 2017; Beaumont et al. 2019), apart from its negative impact on marine biodiversity. Land-based sources contributed to nearly 80% of the anthropogenic microplastics entering the oceans (UNEP Regional Seas Programme 2005; Allsopp et al. 2006; Eunomia 2016). Borrelle et al. (2020) estimated that

in 2016, global plastic waste production ranged from 19 to 23 million tons, a substantial portion of which eventually found its way into aquatic ecosystems.

Growing global environmental concerns have led to increased efforts to monitor and quantify the accumulation of anthropogenic litter in marine environments. Consequently, numerous surveillance programs have been established worldwide in recent decades to assess the extent of litter found in oceans and coastal areas (e.g., Maes et al. 2019). Beach-dune ecosystems are particularly important to monitor in the context of ML or beach litter (BL) due to the various anthropogenic pressures (recreational activities, fisheries, urbanization, etc.) and environmental factors (wind, waves, tides, etc.) that can contribute to their contamination. However, many strategies proposed for collecting stranded ML in coastal areas primarily focus on the subaerial beach (e.g., OSPAR 2010; Galgani et al. 2013a; GESAMP 2019). A notable global initiative addressing the issue of plastic pollution in oceans and coastal areas is the Marine Beach Litter Strategy, which provides valuable data on the extent of the AML problem (Bhuyan et al. 2021; Zielinski et al. 2022; Cesarano et al. 2023; Diem et al. 2023; Mugilarasan et al. 2023, etc.).

Marine litter in the Black Sea

Regarding the marine environment of the Black Sea, land-based waste is identified as the primary contributor, accounting for over 70% of all marine pollution (World Bank 2020). Alongside issues such as nutrient runoff, eutrophication, wastewater discharges and heavy metal accumulation, ML is recognised as a significant and complex environmental concern in the Black Sea basin (BSC 2019; World Bank 2020). The enclosed nature of this sea, with limited water replenishment, restricted vertical mixing and dynamic surface circulation, makes it highly vulnerable to environmental degradation. Additionally, ML pollution is a relatively recent problem for the Black Sea, exacerbating its vulnerability to environmental harm. Consequently, the countries surrounding the Black Sea have undertaken numerous surveys in recent years to gain a comprehensive understanding of the scale of the issue and develop strategies to reduce the inflow of ML into the basin. For instance, the Project "Assessing the vulnerability of the Black Sea marine ecosystem to human pressures – ANEMONE" has played a significant role in these efforts (Paiu et al. 2020; ANEMONE 2021).

Over the past decade (after 2013), the countries surrounding the Black Sea have conducted numerous studies to comprehend the extent of the issue and develop strategies to reduce the inflow of ML into the basin. These studies have revealed concerning levels of anthropogenic litter at various sites along the coastlines of Romania (Muresan et al. 2017; Paiu et al. 2017, etc.), Bulgaria (Brouwer et al. 2017; Simeonova et al. 2017, 2020; Bobchev 2018; Simeonova and Chuturkova 2019, 2020; Toneva et al. 2019; Panayotova et al. 2020; Chuturkova and Simeonova 2021; Bekova 2023; Bekova and Prodanov 2023, etc.), Georgia (Machitadze et al. 2020) and Turkey (Topçu et al. 2013; Terzi and Seyhan 2017; Şahin et al. 2018; Aytan et al. 2020; Gülenç et al. 2020; Öztekin et al. 2020; Terzi et al. 2020; Bat et al. 2022; Erüz et al. 2023, etc.). Significant amounts of floating and seafloor ML, as well as ML sourced from rivers, were identified (BSC 2007; Ioakeimidis et al. 2014; Lechner et al. 2014; Suaria et al. 2015; Moncheva et al. 2016; Öztekin and Bat 2017; Slobodnik et al. 2018; Stanev

and Ricker 2019; Aytan et al. 2020; Berov and Klayn 2020; Doncheva et al. 2020; Miladinova et al. 2020; Raykov et al. 2020; Slabakova et al. 2020; Terzi et al. 2020; Panayotova et al. 2021; Erüz et al. 2022; González-Fernández et al. 2022; Pogojeva et al. 2023). ML was also reported in biota (Tonay et al. 2020; Aytan et al. 2021, 2022; Terzi et al. 2022; Mihova et al. 2023; Zlateva et al. 2023) and in archaeological contexts (Prahov et al. 2021) in the Black Sea area. Georgieva et al. (2023) also highlighted alarming data regarding the widespread distribution of microplastic pollution along the Bulgarian Black Sea Coast. In general, these studies emphasize the necessity of assessing the distribution of micro-, meso- and macrolitter in the Black Sea and their potential risks to humans and coastal ecosystems.

There is a lot of research on mapping anthropogenic debris on coastal dunes (Poeta et al. 2014; de Francesco et al. 2018; Rangel-Buitrago et al. 2018, 2021; Šilc et al. 2018; Menicagli et al. 2019, 2023; Andriolo et al. 2020a, 2020b, 2021a, 2021b; Gonçalves et al. 2020a, 2020b; Turner et al. 2021; Andriolo and Gonçalves 2022; Corbau et al. 2023, Gallitelli et al. 2023; Mancuso et al. 2023, etc.). Unfortunately, the litter on dunes along the Bulgarian Black Sea coast has not been studied until now. Given the results we obtained (mostly land-based), especially for the dunes studied, it is appropriate to avoid the commonly accepted term "Marine Litter" (ML) and use instead the term "MacroLitter on Dunes" (MLD) with the size of the items > 2.5 cm.

UAS approaches in litter mapping

The Unmanned Aerial Systems (UAS), also known as Unmanned Aerial vehicles (UAV) or drones, should be considered not only as an alternative to the conventional visual census but also as a new methodology to advance knowledge on the dynamics of litter, with the potential to play a significant role in providing data for the development of litter models on coasts over time (Gonçalves et al. 2022). A new survey strategy that is based on UAS has been used in recent years to map and detect (manual image screening and machine learning techniques) the abundance and distribution of accumulated macrolitter items on sandy beaches (e.g., Deidun et al. 2018; Fallati et al. 2019; Andriolo et al. 2020a, 2020b, 2021a, 2021b, 2023; Gonçalves et al. 2020a, 2020b; Lo et al. 2020; Escobar-Sánchez et al. 2021; Merlino et al. 2021; Papakonstantinou et al. 2021; Andriolo and Gonçalves 2022). This method has been demonstrated to be efficient in terms of both time and cost while enhancing the accuracy of measurements of coastal macrolitter pollution with RTK mode drones. Andriolo et al. (2020a, 2020b, 2021a) proposed a new framework based on the combined use of UAS and a mobile application to map and quantify marine litter accumulation on coastal dunes. Drones were introduced in Bulgaria for mapping anthropogenic waste and its influence on beach-dune systems in 2018, launching long-term monitoring studies of beach-dune systems (Prahov et al. 2021; Bekova 2023; Bekova and Prodanov 2023; Prodanov et al. 2023a).

Aim of the study

One of the significant gaps in scientific knowledge that requires attention is monitoring macrolitter on coastal dunes in the Black Sea region. This article

aims to fill a gap in the research on dune pollution with macrolitter as well as draw attention to this ignored issue. After worrisome results in the first year, our study switched to mid-term monitoring using a standard visual census aided by UAS photogrammetry. The work aims to obtain an answer to the question “How dirty are the dunes along the Bulgarian Black Sea coast?” and, on the other hand, to understand “How significant is the role of plants on mobile and stabilized dunes for trapping litter?”. The paper aims to present a baseline assessment of abundance, density, spatial distribution, litter sources and categories and an evaluation of cleanliness in 40 dune systems along the Bulgarian Black Sea Coast.

Materials and methods

Dune systems along the Bulgarian Black Sea Coast

According to the latest data from UAS of the Institute of Oceanology at the Bulgarian Academy of Sciences (IO-BAS), the Bulgarian Black Sea shoreline length is 518.7 km (Prodanov et al. 2020a, 2023a, 2023b). Between Cape Sivriburun and Rezovo, approximately 25% (131 km) of its length presents depositional landforms consisting of beaches and 46 beach-dune systems (Prodanov et al. 2023a). During the years, dunes along the Bulgarian Coast have been relatively understudied in geomorphological, morphodynamic (Peychev 2004; Peychev and Peev 2006; Prodanov et al. 2019a, 2019b, 2020b, 2021a, 2021b, 2023a; Prodanov 2023) and geological aspects (Petrov 2013; Valchev 2014, 2015; Sinnyovsky and Sinnyovska 2016, 2017), or as habitats (Gussev and Tzonev 2015; Tzonev 2015a, 2015b, 2015c, 2015d, 2015e, 2015f; Valcheva et al. 2019, 2020, 2021). Anthropogenic macrolitter on coastal dunes has not been studied. Our research focused on the largest dune systems that had been significantly impacted by anthropogenic activities in recent years (Fig. 1). The study sites are located on embryonic dunes, foredunes with dune crest to 7–8 m and backdunes (blowouts and interdune slacks) covered by plants that trap the litter (Prodanov et al. 2023a).

Areas of litter monitoring

The first step was to pre-define the areas for litter monitoring (ALM), also called Sampling Units (SU) in the dune systems (DS) and create vector shape files with study areas as templates for subsequent campaigns (seasons). The MLD surveys were conducted in the spring and autumn seasons from 2018 to 2022 (Fig. 2A). The Bulgarian coastal dune systems have never been subject to monitoring for anthropogenic pollution. This study used the master list in the Guidelines for monitoring marine litter in European seas to classify macrolitter (Galgani et al. 2013a). An area of litter monitoring was planned in 87% of all dune systems along the Bulgarian Black Sea Coast. The 40 selected areas (with a minimum size of 100 m length x 50 m width) were defined according to the spatial distribution of dune landforms varying in height, often covered by dune vegetation that retains significantly more litter than the active beach (Fig. 2B). The area of monitored dunes was assessed at 242 359 m^2 (2.45% of the total area of dunes). They embrace 5 174 m along the coastline, which is equal to 1% of the current length

of the Bulgarian shoreline of 518.7 km (Prodanov et al. 2023a, 2023b). In order to facilitate the creation of a density litter correlation with previous data, the back-dunes of the beaches from the national monitoring program (BLKBG-D10-Marine litter 2016; Simeonova et al. 2020; Kalinov et al. 2021; Bekova 2023; Bekova and Prodanov 2023) were included in the present research.

C. List of Areas of Litter Monitoring

Coastal dune systems	Area, m²	2018	2019	2020	2021	2022
1 Durankulak - North	7 320	+*	+	+*	+	+*
2 Durankulak - South	7 536	+	+*	+	+*	+
3 Krapets - North	8 399	+*	+	+*	+	+*
4 Shabla - North	6 827	+	+*	+	+*	+
5 Shabla - South	5 546	+*	+	+*	+	+*
6 Bolata	1 175	+	+*	+	+*	+
7 Kranevo - Albena	6 114	+*	+	+*	+	+*
8 Asparuhovo (Varna)	5 604	+	+*	+	+*	+
9 Pasha Dere	7 435	+*	+	+*	+	+*
10 Kamchiya (Mouth)	6 708	+	+*	+	+*	+
11 Kamchiya - South (Novo Oryahovo Beach)	4 894	+*	+	+*	+	+*
12 Shkorpilovtsi	5 591	+	+*	+	+*	+
13 Shkorpilovtsi - South	4 826	+*	+	+*	+	+*
14 Kara Dere - North (Byala)	5 368	+	+*	+	+*	+
15 Kara Dere - South (Byala)	5 785	+*	+	+*	+	+*
16 Slanchev bryag	7 753	+	+*	+	+*	+
17 Nessebar - South	7 987	+*	+	+*	+	+*
18 Aheloy	5 612	+	+*	+	+*	+
19 Pomorie Sand Spit	5 114	+*	+	+*	+	+*
20 Burgas Port Wall	5 087	+	+*	+	+*	+
21 Vromos	8 125	+*	+	+*	+	+*
22 Campsite Gradina	9 451	+	+*	+	+*	+
23 Harmanite	5 138	+*	+	+*	+	+*
24 Kavatsite	5 137	+	+*	+	+*	+
25 Alepu	5 412	+*	+	+*	+	+*
26 Arkutino	5 088	+	+*	+	+*	+
27 Ropotamo	5 144	+*	+	+*	+	+*
28 Primorsko (Stamopolu)	13 415	+	+*	+	+*	+
29 Primorsko (Mladost MMC)	5 759	+*	+	+*	+	+*
30 Atliman	5 009	+	+*	+	+*	+
31 Dyavolska Mouth	6 296	+*	+	+*	+	+*
32 Koral	5 120	+	+*	+	+*	+
33 Oazis	5 239	+*	+	+*	+	+*
34 Arapya	6 560	+	+*	+	+*	+
35 Nestinarka	4 438	+*	+	+*	+	+*
36 Ahtopol	5 635	+	+*	+	+*	+
37 Veleka Mouth	7 064	+*	+	+*	+	+*
38 Butamyata	5 089	+	+*	+	+*	+
39 Lipite	3 441	+*	+	+*	+	+*
40 Silistar	5 118	+	+*	+	+*	+

+ UAS mapping, manual collecting and visual census (autumn/spring);
*Manual collecting and visual census – four seasons

Figure 1. Dune areas for litter monitoring along the Bulgarian Coast in 2018–2022.

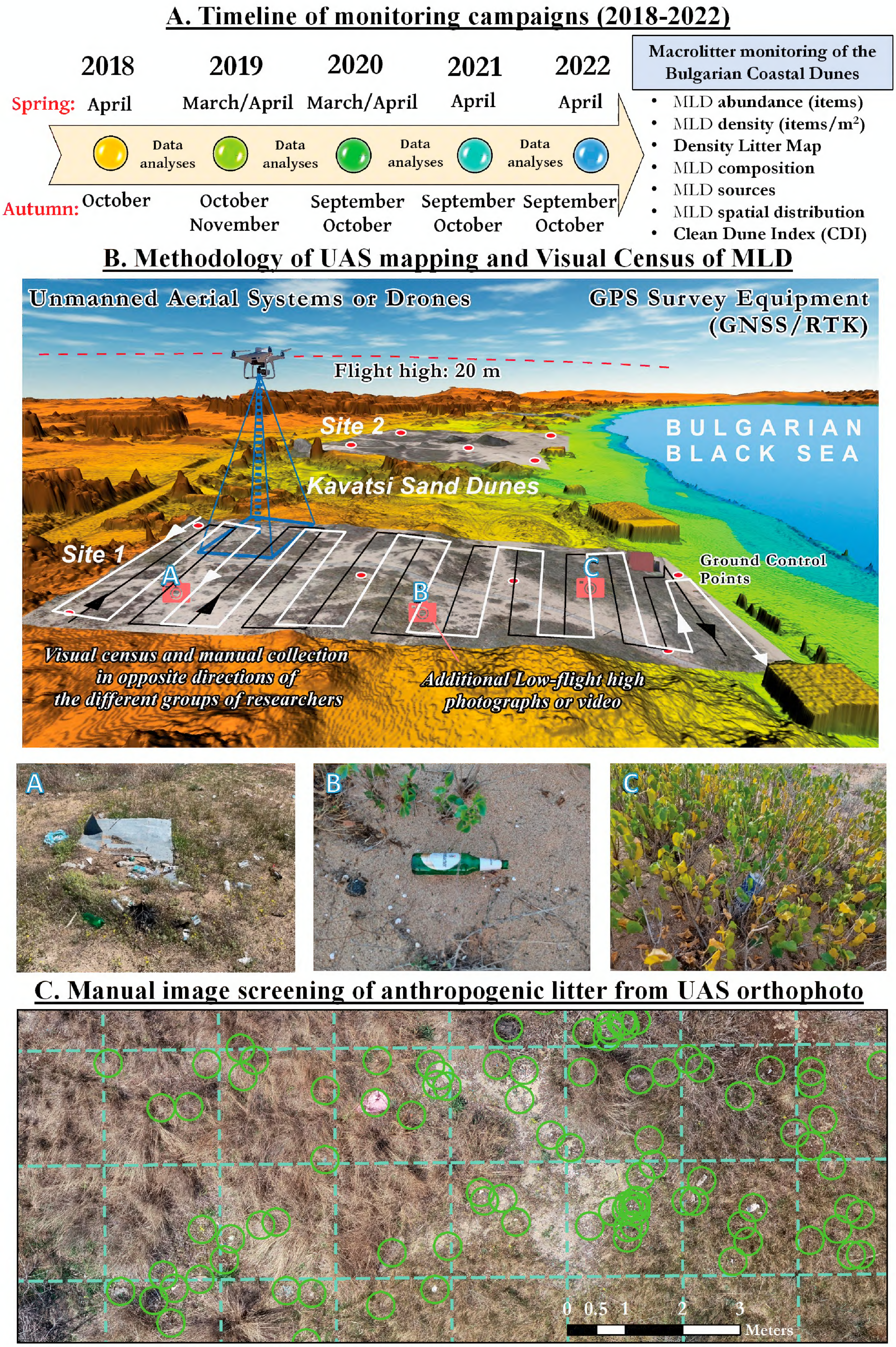


Figure 2. Timeline, methodology of field survey and example of MS procedure along the Bulgarian Coast.

Field surveys

UAS missions and acquired data

A multirotor quadcopter DJI Phantom 4 RTK (DJI-P4RTK), equipped with a 20M pixel camera, was used to collect high-resolution aerial images on dune systems during spring and autumn in the period 2018–2022 (Fig. 2A), following standard procedures (Prodanov et al. 2020a; Gonçalves et al. 2022). A drone-mounted multi-frequency on-board GNSS receiver provided reliable centimetre-level accuracy in positioning. Minimum five ground control points were collected within the study areas by a Hi-Target V90 GNSS RTK system (Fig. 2B). Flying at the height of 20 m with the camera lens placed perpendicular to the flight direction, the drone acquired images (4000 × 3000) with an overlap of 90% front and 90% side. The drone needed about 60 min to complete the study sector (3 flight missions). Following the double-grid photogrammetric survey, imagery in an oblique camera mode was taken from 5 meters above the dune surface to provide a high-resolution image that could be used to support the classification of litter during MS, if necessary.

Agisoft Metashape (v1.5.3-v.1.7.2) was used for the Structure from Motion Multi-View Stereo (SfM-MVS) post-processing stage to generate a Digital Surface Model (DSM) and raster RGB orthophotomosaic (OM) (Fig. 2B, 2C). The nominal spatial resolution of the final mosaic was GSD 0.3 cm raised by low-altitude flight settings. In the period 2018–2022, a large amount of photogrammetric data from different surveys was used, ultimately aiding in wrapping up the monitoring campaigns (Prodanov et al. 2019a, 2019b, 2020a, 2020b, 2021a, 2021b, 2023a, 2023b; Kotsev et al. 2020; Bekova 2023; Bekova and Prodanov 2023; Prodanov 2023).

Visual census, composition and source identification

A primary monitoring strategy consisting of a two-season visual census of MLD larger than 2.5 centimetres was implemented in the second phase. A critical component of the monitoring procedure involved assuring the quality and accuracy of MLD identification through observers. During the five years of the campaigns, the objective was to achieve full coverage of visual census and classification at least once in each area of litter monitoring (Fig. 1). Following the observers in the opposite direction methodology (Fig. 2B), a minimum of three IO-BAS researchers conducted visual census and classifications. The classification of macrolitter was performed using the Marine Litter (ML) categories outlined by Galgani et al. (2013a), ensuring consistency in the classification and characterization of the identified litter. Level 1 - Materials from the MSFD: Artificial polymer materials, Rubber, Cloth/textile, Paper/Cardboard, Processed/worked wood, Metal, Glass/Ceramics, Unidentified.

To investigate for correlation between litter sources on beaches and dunes, we used a bottom-up strategy (found litter types were attributed to possible sources), more specifically, the attribution-by-litter type method, which was in line with the approach provided by Veiga et al. (2016), as it was used for the Bulgarian beaches by Chuturkova and Simeonova (2021). The possible sources are given below:

- Public litter - Items dropped or left by the public on the coast or inland and carried by winds and rivers;

- Fishing litter - Includes commercial and recreational items - e.g., fishing line, nets, rope, weights and buoys;
- Sewage-related debris - Items flushed down the toilet, such as cotton bud sticks, tampons and panty liners;
- Shipping litter - Items dropped or lost from ships;
- Fly-tipped litter - Illegal disposal of waste, including furnishings, pottery and ceramics;
- Medical litter - Includes anything medical such as inhalers, plasters, syringes;
- Non-sourced litter - Items too small or damaged to identify or not obviously attributable to a given source.

Abundance and density of litter

As stated above, the dunes along the Bulgarian Black Sea coast have not been studied in the pollution context. The lack of data and increased anthropogenic pressure on the dunes, particularly over the past three years (Prodanov et al. 2023a), prompted us to ponder two primary aspects: the cleanliness of coastal dunes and the role of vegetation in trapping litter. To understand the cleanliness status of the Bulgarian dunes and how important vegetation is in litter trapping, we investigated the abundance (items) and density (items/m^2) based on the visual census. The values were given as mean ± SD. The visual description of MLD density in the assessment areas is presented in Table 1. The MLD densities in each sampling unit were calculated by Formula (1):

$$D_{ALM,Year,Season} = \left(\frac{Total\ number\ of\ litter}{Assessment\ area}\right), \qquad \left[\frac{number\ of\ items}{m^2}\right] \tag{1}$$

Manual image screening procedure and Litter Maps

Using MS data, Density Litter Maps were generated for each assessment area for analysis of the distribution of MLD (Fig. 3B). To survey the distribution and density of the macrolitter, the orthophotomosaics were subdivided into 2 m × 2 m plots in which the density was quantified in items/m^2 (Fig. 3C), following the workflow of Gonçalves et al. (2020b). The DLM results allowed for the identification of MLD hotspots (or fly-tipped areas) and a future correlation between the density of litter on beaches and dunes (Fig. 3C).

In line with the methodology employed by Gonçalves et al. (2020b), our approach involved the systematic division of each image into a 2-meter square

Table 1. MLD density and visual description adopted for the dune survey.

Density	Visual description (Alkalay et al. 2007)	Adopted visual description for dune surveys (Present study)
0–0.1 items/m^2	no litter is seen	no litter is seen
0.1–0.25 items/m^2	no litter is seen over a large area	no litter is seen over a large dune area
0.25–0.5 items/m^2	a few pieces of litter can be detected	a few pieces of litter can be detected
0.5–1 items/m^2	a lot of waste on the shore	a lot of waste in the dune area
More than 1 items/m^2	most of the shore is covered with plastic debris	most of the dune area is covered with debris

grid, establishing a structured and consistent framework for manual image screening (MS). The operator followed MS, encompassing several key steps:

i. Visual Screening: The operator was tasked with visually examining the RGB orthophotomosaic uploaded in a GIS.
ii. Identification: They were required to identify any litter items present.
iii. Classification: When image quality permitted accurate recognition, the operators classified the litter items according to the categories outlined by Galgani et al. (2013a) and litter sources (Veiga et al. 2016). In this study, when assigning a specific category to an ML object during the image screening was impossible, the feature was characterised with the attribute "unidentified".
iv. Geospatial Marking: A critical component of the procedure involved placing a geospatial placemark at the approximate centre of each identified item within a Geographic Information System (GIS) environment (Fig. 2C).
v. Shapefile Creation: Operators generated individual shapefiles for each designated area of litter monitoring.

This comprehensive procedure facilitated the precise mapping of MLD and its precise localization, enabling the creation of a Dune Litter Map (as illustrated in Fig. 3A). Furthermore, it allowed for the analysis of BL density, as depicted in Fig. 3B.

Results

Abundance and density of macrolitter on dunes

The launch of monitoring on dunes in 2018, aided by unmanned aerial systems, provided accurate data on the MLD abundance, density, composition and spatial distribution. The results provided a new perspective on the pollution mechanism existing between the shoreline and the backdunes. The presented results for abundance, litter density and Clean Coast Index are based on visual census data, as well as MS data for analysis of the spatial distribution of MLD.

It was determined that there was a long-term trend toward an increase in both key parameters: abundance (the number of litter items) and density of macrolitter (items/m^2), shown in Fig. 4, Appendix 1 and 2. The abundance reached its maximum during 2021 with average values of 3 710 ± 2 678 items per assessment area. The average abundance experienced an increase of 39% between 2018 and 2021. It is pertinent to acknowledge that this period coincided with the occurrence of force majeure circumstances, notably the COVID-19 epidemic, which exerted significant pressure on the Bulgarian Black Sea coast due to the influx of local tourists.

Over 5% of the dune area has been under strong anthropogenic influence in recent years due to recreational activities and interventions, camping and inadequate management of dunes (Prodanov et al. 2023a). Along the Bulgarian coast, these factors have a negative effect on the density and concentration of hotspots. The map of average densities (Appendix 1) illustrates the significant imprint left by tourists in the most frequently visited beach-dune systems. In 15% of the assessment areas, the highest litter density (D_{av} > 1 items/m^2) was recorded: (24)

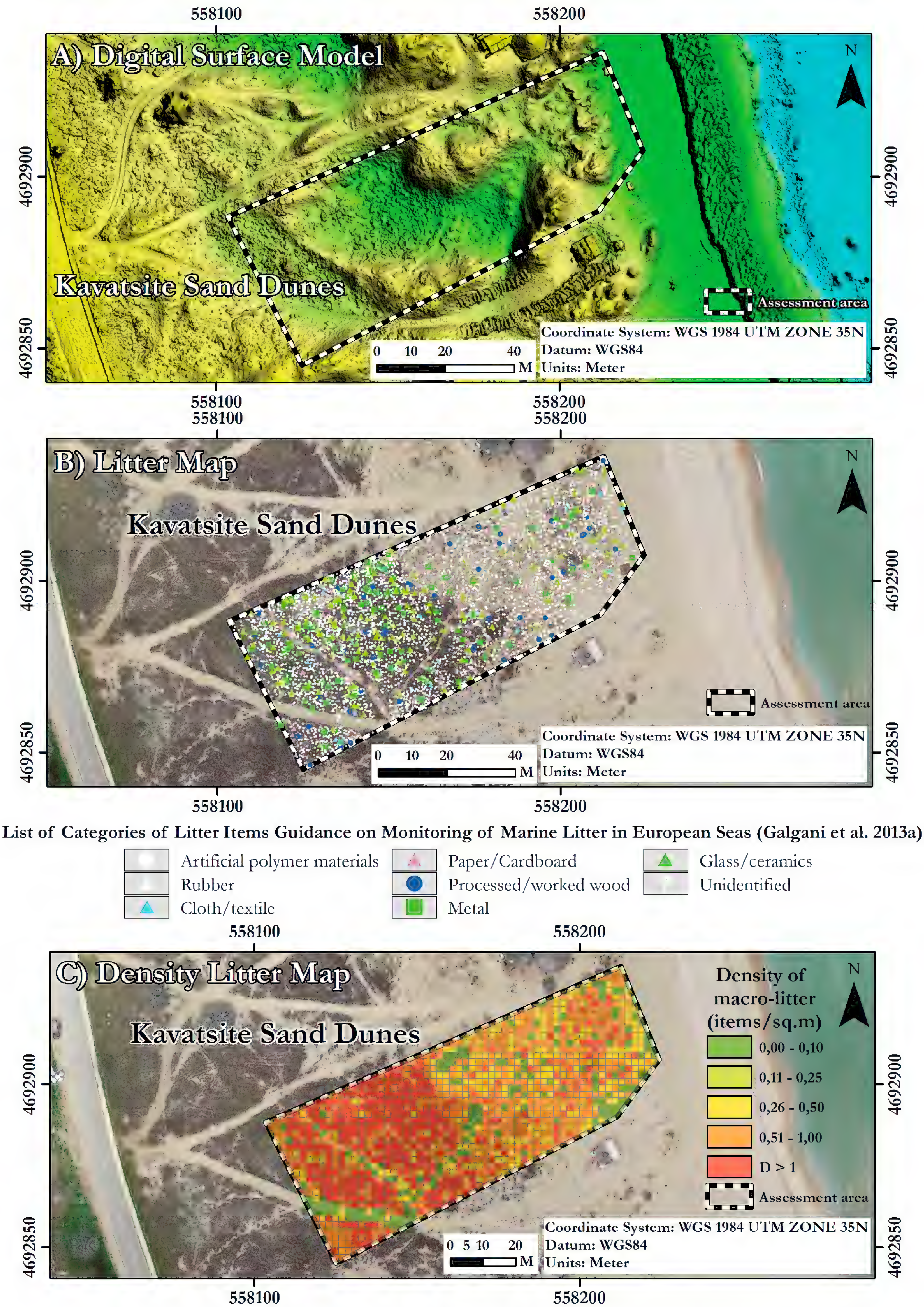


Figure 3. Example of manual screening and Density Litter Map on Kavatsite dunes in April 2021.

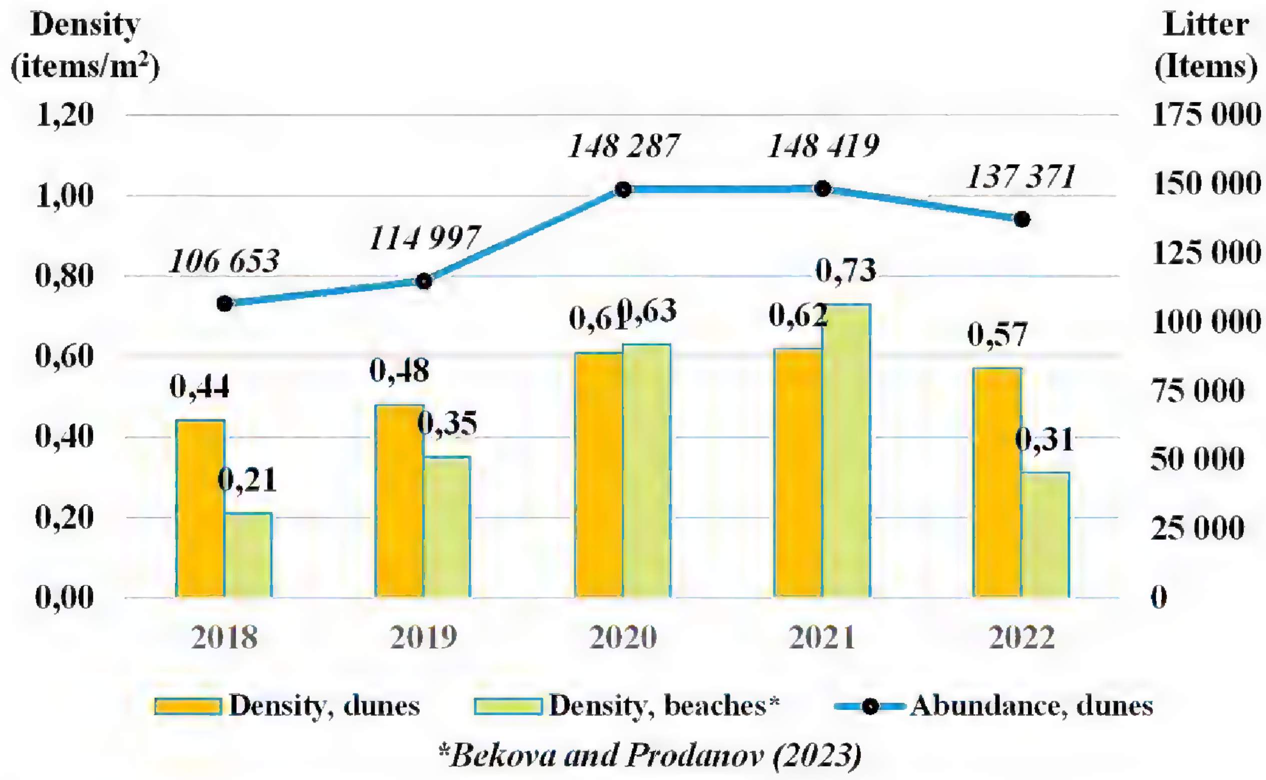


Figure 4. Mid-term variation (2018-2022) of total abundance (items) and average densities (items/m2) based on visual assessment of macrolitter on dunes along the Bulgarian Coast.

Kavatsite – 1.36; (17) Nessebar - South - 1.25; (6) Bolata – 1.23; (8) Asparuhovo (Varna) - 1.22; (16) Slanchev bryag - 1.25; and (20) Burgas Port Wall - 1.03.

Regarding density, most assessment areas were categorised as “a few pieces of litter can be detected” - 38% (0.26–0.5 items/m^2) and “a lot of waste in the dune area” - 30% (0.5–1 items/m^2). They were prevalent along the entire coastline, especially near campsites and resorts such as Krapets, Arkutino, etc. Still, there were relatively clean dunes with a low density of macrolitter, despite the strong anthropogenization, lack of maintenance and systematic cleaning. They were categorised as “no litter is seen over a large dune area” - 12% (0.1 to 0.25 items/m^2) and “no litter is seen” - 5% (0 to 0.1 items/m^2). A total of two assessment areas were categorised as “no litter” representing areas with low tourist impact: (39) Lipite and (27) Ropotamo (Appendix 1).

Seasonal variation of macrolitter on dunes

According to Simeonova et al. (2017), the amount of litter on the beach had the highest values in summer. Terzi and Seyhan (2017) and Aytan et al. (2020) reported an increase in pollution during the spring season in the southwestern part of the Black Sea. Panayotova et al. (2020) found that Asparuhovo Beach was the most polluted in spring. Our research indicated that the highest density ($D_{av,18–22,Autumn}$: 0.62 items/m^2) occurred in autumn, after the end of the tourist season. In winter, strong north, northeast and east winds blew some of the litter off the dunes and spring monitoring campaigns registered lower densities ($D_{av,18–22,Spring}$: 0.46 items/m^2). This study found a significant seasonal variation in MLD density of approximately 25%, with the greatest litter amount discovered in autumn, following the peak of the tourist season.

Composition of macrolitter on dunes

The identified MLD was classified according to the Master List of Categories of Litter Items - Level 1 by MSFD Technical Subgroup on Marine Litter (Galgani et al. 2013a): Artificial polymer materials, Rubber, Cloth/textile, Paper/Cardboard,

Processed/worked wood, Metal, Glass/ceramics, Unidentified. It was not surprising that the high dominance of plastic litter (artificial polymer materials) on the beach (Simeonova et al. 2017, 2020; Simeonova and Chuturkova 2019; Toneva et al. 2019; Panayotova et al. 2020; Chuturkova and Simeonova 2021; Kalinov et al. 2021) was also found on the dunes. Over the past five years, low variations in the amount of plastic polymer litter were observed, and in terms of percentage, it was the most prevalent waste along the Bulgarian Black Sea coast (Figs 5A, 6; Appendix 3). Special consideration should be given to the category "Paper/Cardboard" - 6.17%. That was the second most prevalent type of litter on our dunes. Due to inadequate waste-disposal facilities, a significant amount of that litter category was wind-transported from the active beach to the dunes. The unique conditions provided by the plants on the dunes aided in the trapping of paper waste. Rubber, Cloth/textile, Processed/worked wood, Metal, and Glass/ceramics were scarce on the dunes and did not exceed the 2% threshold (Fig. 5A; Appendix 3).

Sources of macrolitter on dunes

The results obtained during the monitoring campaigns are an initial assessment of the sources, composition and density of macrolitter on the Bulgarian Black Sea dunes. Understanding how increasing human pressure affects sensitive dune habitats is of the utmost importance when studying coastal dunes in the context of litter pollution. Sources of MLD were separated into two main classes: land-based sources (LS) and sea-based sources (SS). To a large extent, SS were dominated by waste discarded by fishing and shipping. Small-mass macrolitter, such as fishing nets and ropes, was successfully transported to the dunes. Our study found that the high frontal dunes covered with vegetation played an important trapping role in the retention of SS litter. SS did not exceed 5% of the total litter during any of the monitoring campaigns, with an average prevalence of 4.79%. At the same time, recreational areas, resorts and campsites were the main LS (95.21% of the total amount of macrolitter).

Even though the produced data were a pilot for the dune systems, it was essential to investigate the connection between the litter on the dunes and the litter on the beaches adjacent to them (if possible). Therefore, we went beyond the previous studies of beach litter (Panayotova et al. 2020; Chuturkova and Simeonova 2021) and examined the differences in the obtained results in an eco-geomorphological aspect. According to Veiga et al. (2016), the summary data for the period 2018–2022 is shown in Fig. 5B. The Public litter comprised the majority of MLD, accounting for 44.3% of the total number of items registered during that time. In contrast to the beach, where Fly tipped litter was 5.2% of the total amount (Chuturkova and Simeonova 2021), on dunes, that source generated 33.6% of litter items. The contribution of the other sources (Medical - 13.6%, Fishing - 2.8%, Shipping - 1.1, and Sewage Related Debris - 0.4%) was considered insignificant. Therefore, the estimated Non-sourced anthropogenic litter was 4.2%.

Spatial distribution of MLD

In contrast to active beaches, which are dominated by wave processes and tourism, dunes are dominated by the trapping function of dune vegetation. But are plants the most essential for waste retention?

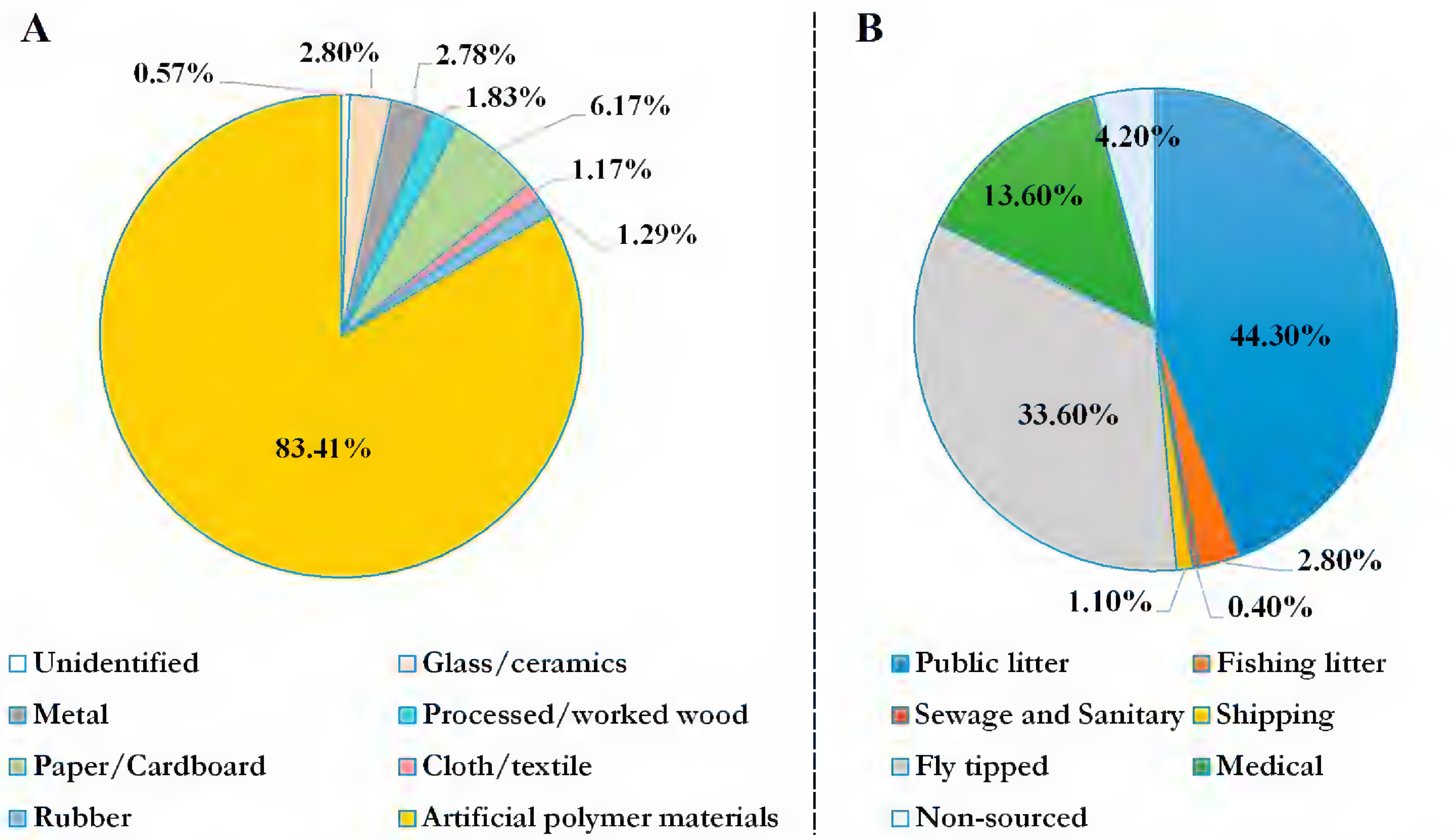


Figure 5. A average percentage distribution (%) of MLD materials according to Master List of Categories of Litter Items (Galgani et al. 2013a) for 2018-2022 **B** sources of MLD aggregated in 2018–2022.

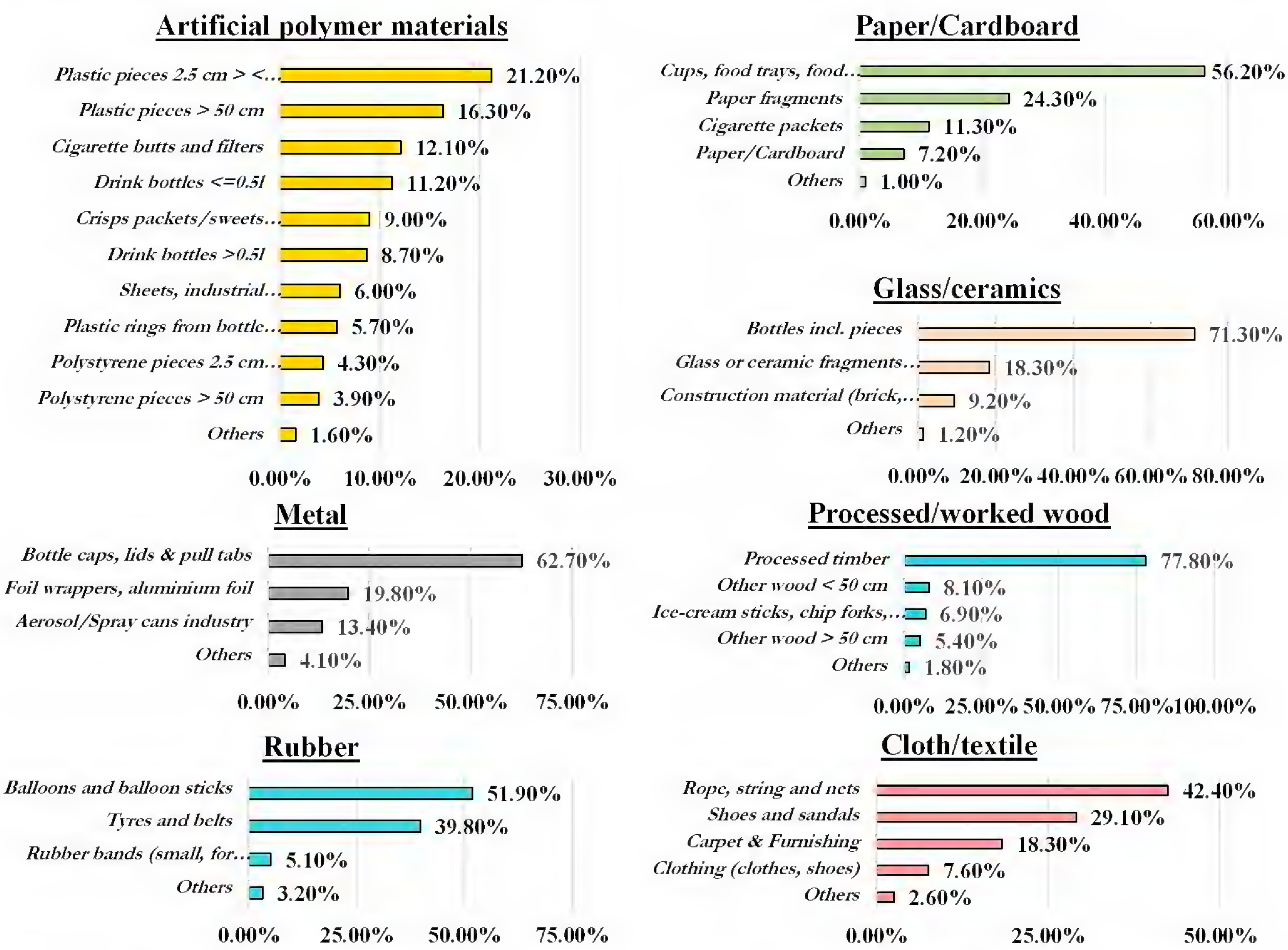
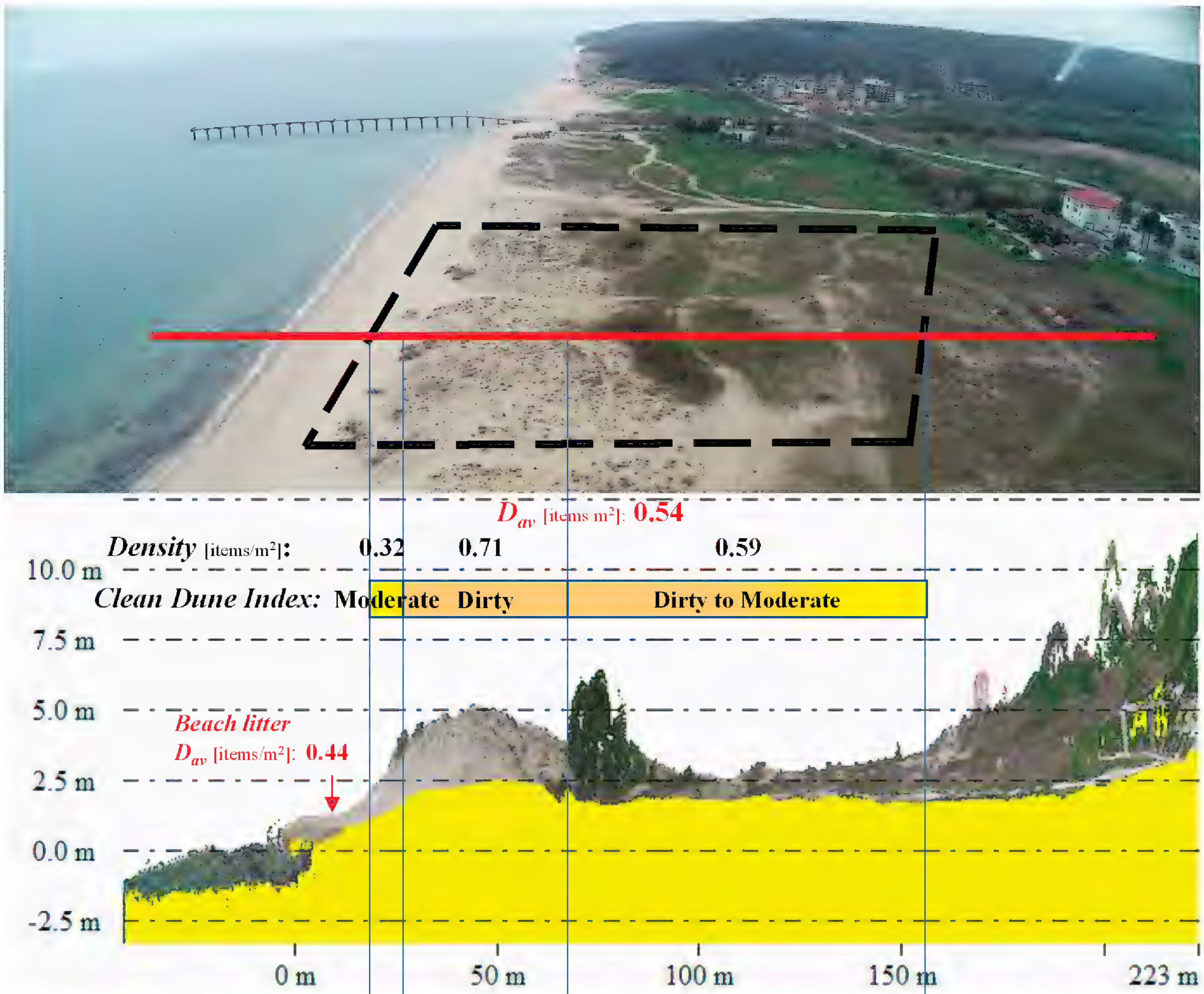


Figure 6. Average percentage distribution (%) of MLD subcategories according to Master List of Categories of Litter Items (Galgani et al. 2013a) for 2018–2022.

Geomorphologically, the main types of dunes that comprise the accumulative landscape are embryonic, foredunes (frontal) and secondary (backdunes), which are not currently subject to wave action. From an ecological point of view, dunes are habitats with unique vegetation (Gussev and Tzonev 2015; Tzonev 2015a, 2015b, 2015c, 2015d; Valcheva et al. 2019, 2020, 2021). The embryonic dunes represent the initial barrier against marine debris. They "armour" the frontal dunes and retain only 16% of the total litter items (Fig. 7). The average



Litter Categories	Embryo 16%	Foredunes 28%	Backdunes 55%	Type of dunes / Litter distribution, [%]
Artificial polymer materials	8%	18.5%	73.5%	
Rubber	28%	53%	19%	
Cloth/textile	3%	46%	51%	
Paper/Cardboard	11%	81%	8%	
Processed/worked wood	13%	16%	71%	
Metal	8%	3%	89%	
Glass/ceramics	16%	8%	76%	
Unidentified	44%	2%	54%	

Figure 7. A general profile with CDI categorisation, average densities, composition and spatial distribution of litter on dunes along the Bulgarian Black Sea Coast for the monitoring period 2018–2022 (example: Shkorpilovtsi beach-dune system).

density was estimated to be 0.23 items/m^2 with Rubber, Paper/Cardboard, Processed/worked wood and Glass/ceramics dominating the litter composition.

The highest litter density was observed on the foredunes, with an average value of 0.80 items/m^2 (28% of total items). The backdunes contained the highest amount of litter items (55%), with an average density of 0.58 items/m^2. Land-based sources were the main cause of that great abundance of litter. A significant portion of litter was found in the dune vegetation, increasing the litter density in the backdunes by 20–25% compared to the beaches and foredunes (see example DLM in Fig. 3B). It should be noted that there were small areas where fly-tipped waste was observed in 38 out of 40 assessment areas, negatively impacting the beach (Fig. 2A, B).

Discussion

Effectiveness of drones in litter mapping on dunes

In our examination, drones are practical and convenient for operation. However, there is still uncertainty and subjectivity when it comes to classifying small-size litter, especially in stabilized vegetated dunes. The discussion highlights the advantages of using drones for pollution research. One more reason for the future application of drones for litter mapping on the dunes is their protective nature, and manual collecting should be avoided. An analysis of collected data reveals that the MS procedure was highly effective, identifying 92.1% of the BL items initially identified by a visual survey (Fig. 8). Notably, the MS procedure was supported with low-altitude video imaging at 5 m above each beach surface using an oblique camera, which an operator used to classify items more accurately. The identification of BL from the video contributed an additional 2%, as the final score increased to 94.1%. Furthermore, the "hidden" macro litter in the dune plants compelled us to reduce the flying height to 20 m (in some areas to 10 m), resulting in very high-resolution orthophotomosaics between

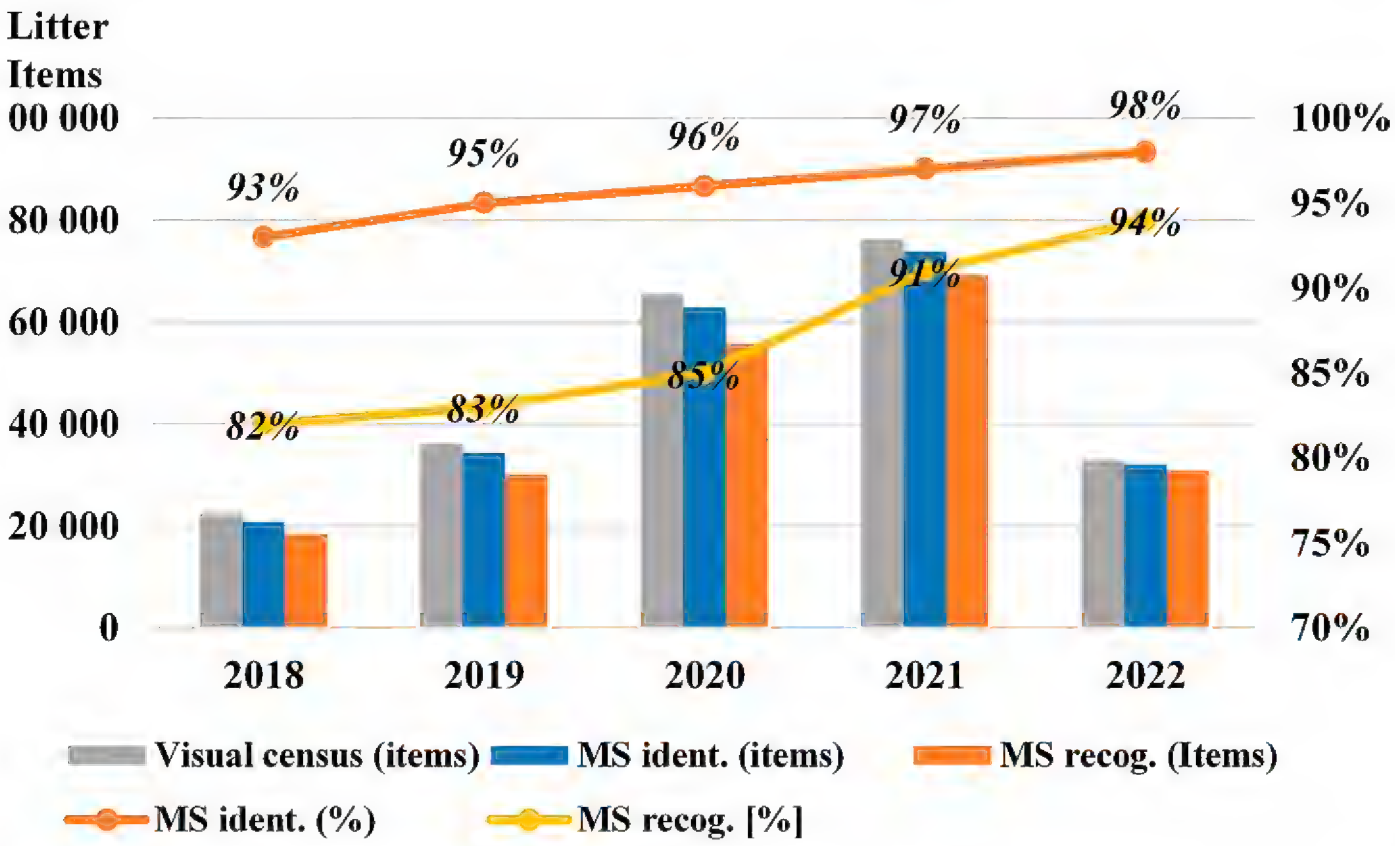


Figure 8. Comparison between the results from visual census and MS procedure of RGB orthophotomosaics along the Bulgarian Black Sea Coast.

0.3–0.5 cm/pix GSD. Of course, very low-altitude missions necessitated longer flight times, but, on the other hand, that expedited the macrolitter image screening process from orthophotomosaics. This recognition was successful on 84% of the items in our study. However, it is important to note that the operator was familiar with the categories of objects commonly found along Bulgarian coastlines and dunes (Bekova 2023; Prodanov and Bekova 2023) and actively participated in the field manual collecting and visual census.

From another point of view, the development of orthophoto and DSM also enables an objective definition of the various dune types (embryonic, foredunes and backdunes) and features (dune blowouts, trails, or dune pathways). Future research could combine litter mapping/monitoring with coastal geomorphological studies (Bastos et al. 2018; Duo et al. 2018; Gonçalves et al. 2018, 2020a, 2020b; Laporte-Fauret et al. 2019; Pagán et al. 2019; Andriolo et al. 2020a, 2020b; Bekova and Prodanov 2023; Corbau et al. 2023; Prodanov et al. 2023a, etc.) and coastal dune vegetation mapping (Meng et al. 2017; Suo et al. 2018) using drone data.

Still, there is no sustainable solution for automatically detecting and classifying litter on dunes. In contrast, for beaches, uniform standards of operation are being discussed to enhance the reliability of research (Gonçalves et al. 2022, etc.). Despite the successful application for litter mapping (Andriolo et al. 2020a, 2020b, 2021a; Gonçalves et al. 2020a, 2020b, etc.), we believe that the use of an automated object-based image segmentation technique and the service of a machine-learning classifier is not yet sufficiently improved to identify and recognize litter on/in high dune vegetation (white/grey/wooded dunes), which comprises more than 70% of the assessment areas along Bulgarian coast (Figs 2, 7).

Our experience shows that the opportunities of the UAS-based methodology presented in the study outweigh the disadvantages. The main line of controversy is between "time-consuming manual collecting with intrusive impact on dunes" versus "fast UAS mapping with minimal dune impact". According to the results of our research, traditional field measurements could, under ideal conditions, survey two study sites per day, while drone surveys mapped four assessment areas per day, including beaches that were close to one another (Bekova and Prodanov 2023). Due to the sensitive coastal dune habitats, we need to continue to conduct our research using remotely non-destructive drone-based technology with minimal anthropogenic impact, following a trend away from minimizing manual sampling, which inevitably has a negative impact on dune habitats.

Development of a Clean Dune Index (CDI) for evaluation of the Bulgarian Black Sea coastal dunes

Data pertaining to the density, composition and sources of litter on the dunes have been presented as a means to assess the level of dune cleanliness. As Alkalay et al. (2007) proposed, a Clean Coast Index (CCI) was calculated based on the density of anthropogenic litter covering the beaches. But should CCI threshold values actually apply to dunes?

The configuration of the coastal system is influenced by various factors such as morphology, anthropogenic activities, climatic conditions and vegetation type. However, it is important to note that the impact of these factors

on beach and dune forms is not uniform. Thus, it can be concluded that the CCI proposed by Alkalay et al. (2007) may not be suitable due to its mapping of different eco-geomorphological components. The present study established significant differences in density values, exceeding 50%, between dunes and beaches in some locations. This finding is consistent with the results reported by Simeonova et al. (2020), Kalinov et al. (2021), Bekova and Prodanov (2023) in their respective studies. The beach-dune system located at Veleka Mouth is considered to be one of the emblematic cases. According to Simeonova et al. (2020), beach litter density was estimated to be 0.09 items/m^2 in 2019. Bekova and Prodanov (2023) conducted UAS orthophoto screening and identified a density of 0.55 items/m^2. At the same time, our study found a density value of 0.66 items/m^2 of macrolitter on the dunes.

A comparative analysis was performed using data from standardised UAS mapping of beach and dune assessment areas (Table 2) to determine the extent to which dunes are more polluted than beaches and whether that was valid for all beach-dune systems. The observed dissimilarities in density between BL and DL suggested that the threshold values of the widely accepted CCI index (Alkalay et al. 2007) were not fully applicable for evaluating the spatial distribution of MLD. In order to conduct a comprehensive evaluation of cleanliness, a Clean Dune Index (CDI) was developed using the CCI (Alkalay et al. 2007) as a basis. However, the threshold values were increased to account for the significant trapping role of dune vegetation that spans up to 200 m inland and reaches up to 0.5 m in height. The primary objective of the CDI, as introduced for the first time in this study, is to provide data consumers with a clear indication that the outcomes exclusively pertain to dune formations and do not encompass any statistical information concerning litter disposal on the beach. Formula (2) was used to determine the CDI of each area of litter monitoring during the monitoring campaigns.

$$CDI_{ALM\ Year\ Season} = \left(\frac{Total\ number\ of\ litter\ items}{Area\ of\ assessment}\right) \times K \tag{2}$$

where K is a coefficient and equals 20, the assessment area (m^2) between the dune toe (foot line of the seaward dune slope) and the dune hee of the backdunes (or minimum 50 m length inland) was estimated, as shown in Fig. 3A. The disparity between the suggested CDI and CCI (Alkalay et al. 2007) was solely attributed to the tolerance in threshold values and interpretation of the definition.

Table 2. Comparison of average litter density on dunes and beaches (Bekova and Prodanov 2023) in 2018–2022 (see the full table in Appendix 4).

Year	$D_{beaches}$ ± SD	D_{dunes} ± SD
2018	0.21 ± 0.14	0.44 ± 0.28
2019	0.35 ± 0.23	0.48 ± 0.30
2020	0.63 ± 0.39	0.61 ± 0.40
2021	0.73 ± 0.43	0.62 ± 0.40
2022	0.31 ± 0.22	0.57 ± 0.40
Average density	0.44 ± 0.28	0.54 ± 0.35
Total Average Percentage difference, [%]	21.12% ~ 20%	

The thresholds of the CDI were increased by the total average percentage difference between the density of macrolitter found on beaches and dunes, which was established to be 20% for the Bulgarian coastal dunes (Appendix 4). The variability of the 20% difference may be subject to modification in accordance with the specific eco-geomorphological conditions of various countries, dune systems/dune habitats. It is recommended that litter surveys be conducted on the beach and back dunes whenever possible. It will provide insight into the general pattern of macrolitter distribution in beach-dune systems.

Are the dunes clean or dirty along the Bulgarian Black Sea coast?

Based on an in-depth evaluation of data obtained from the mid-term monitoring, the Bulgarian Black Sea dune systems were categorised as "moderate" with CDIav,18–22: 10.89 (Fig. 9; Appendix 1). Throughout the monitoring campaigns spanning from 2018 to 2022, an equal distribution was observed among the primary categories of CDI, namely, very clean to clean (20%), moderate (45%) and dirty to extremely dirty (35%). Nevertheless, trends could be discerned among the sampling unit in relation to their proximity to leisure areas, such as Kavatsite and Gradina campsites, etc.

Moderately clean dunes at Dobrudzha Coast

The elongated dune systems were classified as "moderate" Dobrudzha dunes (Fig. 9; Appendix 1). They are located in the following assessment areas: (1) Durankulak - North, (2) Durankulak - South, (3) Krapets - North, (4) Shabla - North and (5) Shabla - South. The beach-dune systems are oriented in a meridional direction, extending from Durankulak to Shabla. The moderate pollution observed on the dunes at the area assessments (3) Krapets-North could be attributed to the unauthorised camping activities taking place in the backdunes. The beach-dune systems found in the northernmost regions were typically less affected by anthropogenic activities owing to the relatively lower influx of tourists compared to the southern coast. The units (6) Bolata stands in contrast to the aforemen-

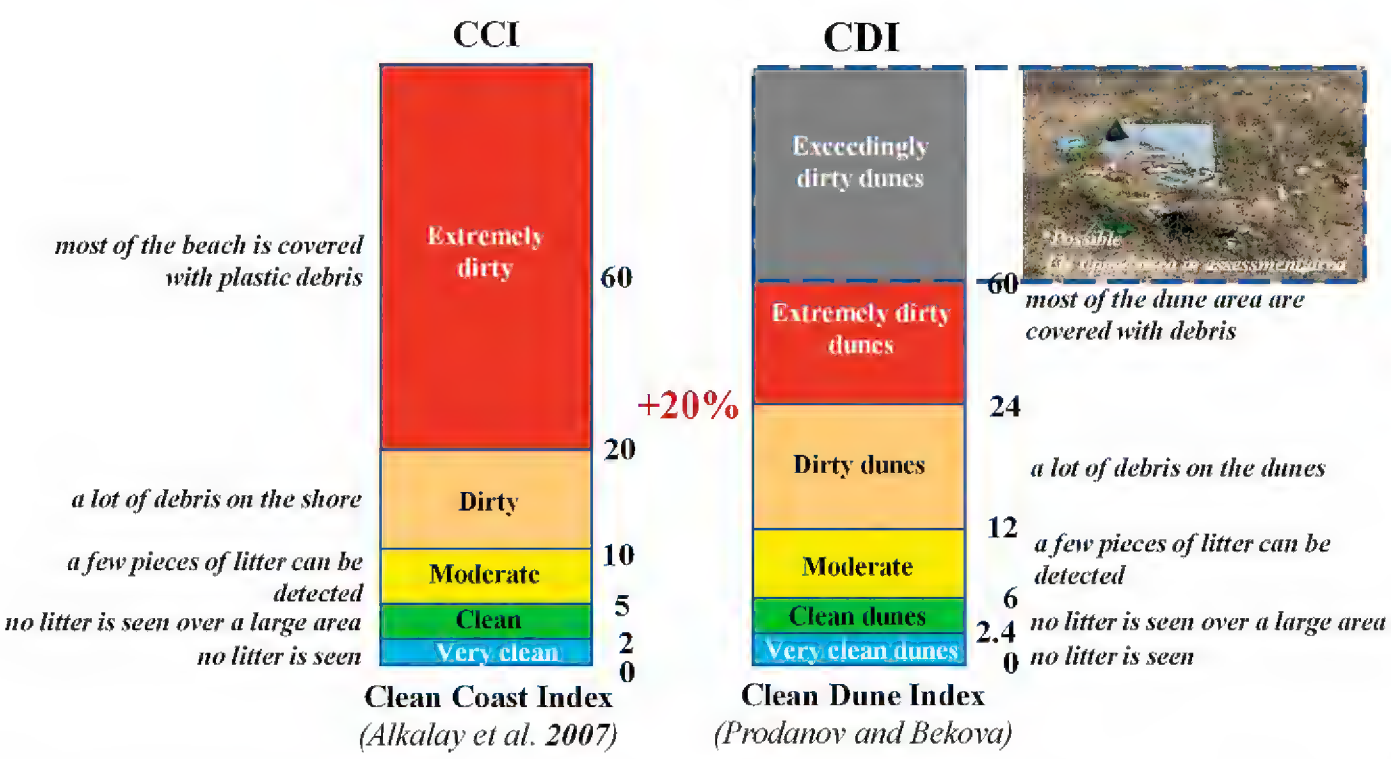


Figure 9. Clean Dune Index (CDI) for evaluation of the Bulgarian Black Sea coastal dunes with an additional class of Exceedingly dirty dunes.

tioned statements. Bolata dunes are well-shaped compact sand forms covered by dense vegetation. Recently, vehicle access has been allowed in the immediate vicinity. Consequently, there is an increase in tourist pressure. Bolata Cove is characterised by its scenic beauty and limited spatial extent. The dynamic of debris within the cove is constrained by the presence of high cliffs behind the dunes, designated as “extremely dirty” status ($CDI_{av,Bolata,18–22}$: 24.69).

Dunes along the Central Coast

This group comprises the coastal dunes stretching from Cape Galata to Cape Emine (Fig. 9; Appendix 1). The preserved coastal dunes of the central coast section encompass the assessment areas (9) Pasha Dere, (10) Kamchiya (Mouth), (11) Kamchiya - South (Novo Oryahovo Beach), (12) Shkorpilovtsi, (13) Shkorpilovtsi - South, (14) Kara Dere - North (Byala), (15) Kara Dere - South (Byala). The study identified two distinct areas, namely (14) Kara Dere - North (Byala) and (15) Kara Dere - South (Byala), based on their geographical location. Due to the comparable CDI values, the scope of the research was broadened to encompass the clean dunes of Pasha Dere and Kara Dere, which had been protected from pollution owing to the limited number of tourists. The CDI values observed in these assessment areas varied between 2.77 and 7.42.

Extremely dirty dunes at Slanchev bryag and Nessebar Coast

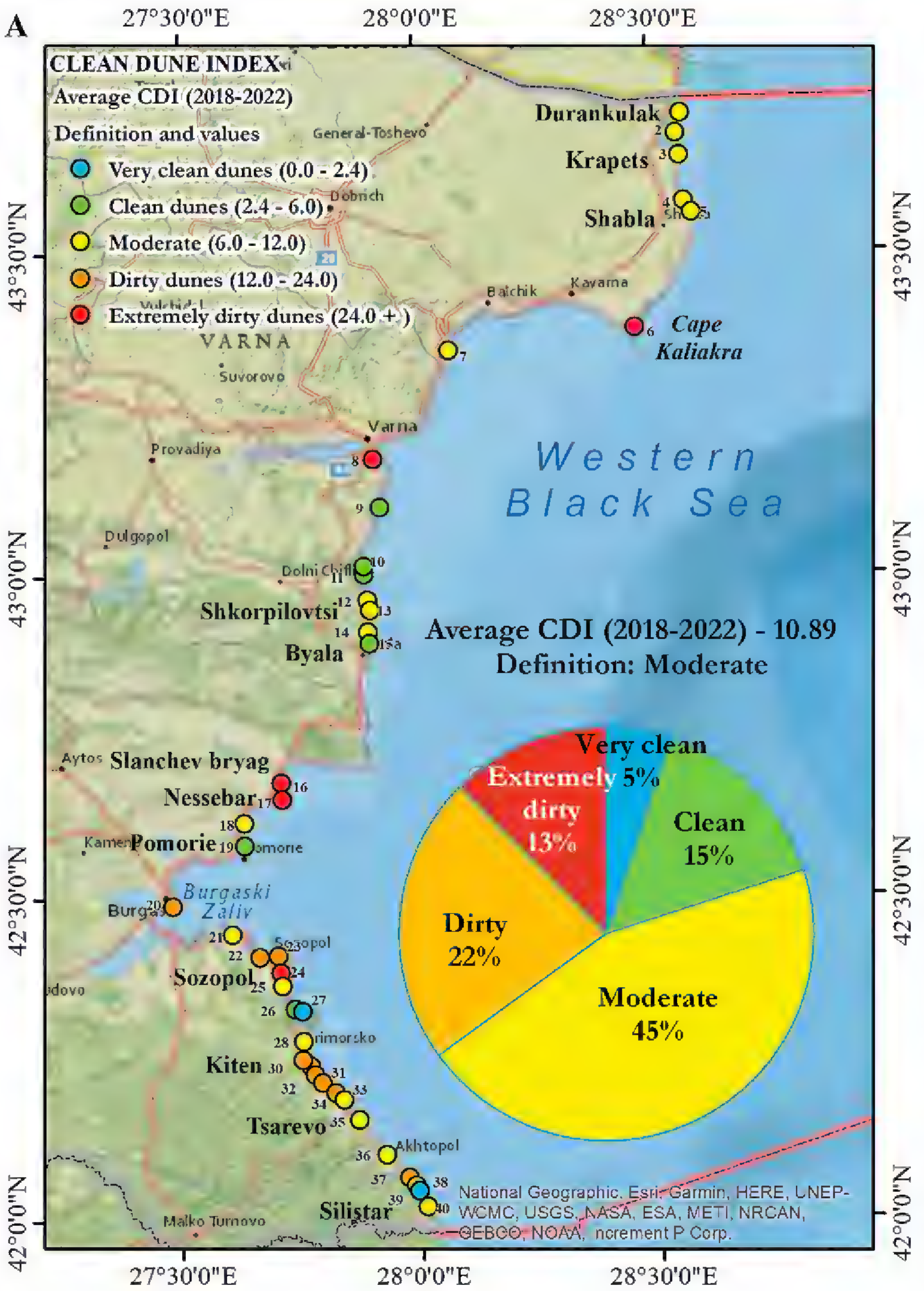
A significant human footprint was detected on the assessment units (16) Slanchev Bryag and (17) Nessebar–South, located south of Cape Emine (Fig. 9; Appendix 1). The anthropogenic impact was reflected in “extremely dirty” dunes at the abovementioned assessment areas ($CDI_{av,Slanchev\ bryag,18–22}$: 24.09 and $CDI_{av,Nessebar,18–22}$: 25.01). The plastic litter most commonly found in the environment comprises cigarette butts, plastic bottles and medical masks. The insufficiency of waste disposal facilities for tourists is a pressing issue. In addition, the coastal region is subject to severe wind conditions that facilitate the transportation of substantial quantities of litter from the beach to the inland backdunes.

Dirty dunes along Burgas-Medni Rid Coast

The present group provides a concise overview of the dune systems located within the assessment areas: (20) Burgas Port Wall, (21) Vromos, (22) Campsite Gradina, (23) Harmanite, (24) Kavatsite, (25) Alepu, (26) Arkutino and (27) Ropotamo (Fig. 10). The distribution of MLD did not exhibit a discernible trend, as evidenced by the CDI values encompassing from 0.95 to 27.22. Notably, the Bulgarian coastal dunes showed high and low cleanliness levels.

“Extremely dirty” dunes at Kavatsite. The locality is emblematic, with the wide beach strip visited by thousands of tourists in summer. The well-developed, irregularly dune ridges have “sheltered” the vast amount of litter from the beach. The DLM (Fig. 3C) demonstrated the role of plants with a considerable supply of litter from the beach. The index reached alarming values, $CDI_{av,Kavatsite,18–22}$: 27.22. It is also an important fact that in the dune systems (24) Kavatsite and (16) Slanchev Bryag, the highest values of plastic waste (92%) for the Bulgarian coast were recorded (Fig. 9).

A



B Clean Dune Index for Bulgarian Black Sea coastal dunes

Dune system	2018	2019	2020	2021	2022	Average	CDI
1 Durankulak - North	4.52	4.87	6.04	6.60	8.73	6.15	Moderate
2 Durankulak - South	4.50	4.85	6.02	6.99	7.87	6.05	Moderate
3 Krapets - North	6.41	7.84	10.55	11.51	7.42	8.75	Moderate
4 Shabla - North	5.51	5.94	7.37	7.00	6.38	6.44	Moderate
5 Shabla - South	4.49	4.83	6.91	7.11	6.75	6.02	Moderate
6 Bolata	18.42	19.84	26.59	29.72	28.89	24.69	Extr. Dirty
7 Kranevo - Albena	7.10	7.64	10.28	9.01	8.21	8.45	Moderate
8 Asparuhovo (Varna)	17.17	18.51	31.13	25.64	29.24	24.34	Extr. Dirty
9 Pasha Dere	2.37	2.55	3.17	3.01	2.74	2.77	Clean
10 Kamchiya (Mouth)	3.03	3.26	4.05	3.84	3.50	3.54	Clean
11 Kamchiya - South	2.93	3.35	5.82	5.77	6.71	4.91	Clean
12 Shkorpilovtsi	6.31	6.80	8.44	8.01	7.30	7.37	Moderate
13 Shkorpilovtsi - South	6.36	6.84	8.50	8.07	7.35	7.42	Moderate
14 Kara Dere - North (Byala)	4.21	4.53	7.86	6.39	7.16	6.03	Moderate
15 Kara Dere - South (Byala)	3.05	3.28	4.08	3.87	3.53	3.56	Clean
16 Slanchev bryag	18.63	20.07	24.91	30.47	26.39	24.09	Extr. Dirty
17 Nessebar - South	20.32	21.88	27.16	25.79	29.90	25.01	Extr. Dirty
18 Aheloy	7.46	8.03	9.97	11.10	8.63	9.04	Moderate
19 Pomorie Sand Spit	3.18	3.42	4.25	5.80	6.70	4.67	Clean
20 Burgas Port Wall	17.66	19.02	23.61	22.42	20.44	20.63	Dirty
21 Vromos	5.47	5.89	7.31	10.14	6.33	7.03	Moderate
22 Campsite Gradina	11.93	12.85	15.95	17.30	13.81	14.37	Dirty
23 Harmanite	13.00	14.00	17.38	16.50	15.04	15.18	Dirty
24 Kavatsite	19.91	22.63	30.33	31.68	31.58	27.22	Extr. Dirty
25 Alepu	6.55	7.06	8.76	9.91	7.58	7.97	Moderate
26 Arkutino	4.69	5.05	6.27	5.95	5.43	5.48	Clean
27 Ropotamo	0.61	0.65	0.81	1.95	0.70	0.95	Very clean
28 Primorsko (Stamopolu)	9.55	10.29	13.13	12.13	11.05	11.23	Moderate
29 Primorsko (Mladost MMC)	11.01	11.86	14.72	13.98	12.74	12.86	Dirty
30 Atliman	10.60	11.42	14.17	13.46	12.27	12.38	Dirty
31 Dyavolska Mouth	13.59	14.63	18.17	17.25	15.73	15.87	Dirty
32 Koral	10.90	11.74	14.58	13.84	12.62	12.74	Dirty
33 Oazis	16.45	17.72	21.99	20.89	19.04	19.22	Dirty
34 Arapya	10.05	8.95	11.11	10.55	9.62	10.06	Moderate
35 Nestinarka	9.22	9.93	12.32	11.70	10.67	10.77	Moderate
36 Ahtopol	5.48	5.90	9.02	9.28	6.34	7.20	Moderate
37 Veleka Mouth	12.22	13.16	16.33	15.51	14.14	14.27	Dirty
38 Butamyata	7.41	7.98	9.90	9.41	8.57	8.65	Moderate
39 Lipite	1.02	1.10	1.57	1.30	1.19	1.20	Very clean
40 Silistar	9.60	10.34	12.84	12.19	11.11	11.22	Moderate
Average CDI values	8.82	9.51	12.33	12.33	11.49	10.89	Moderate

Figure 10. Evaluation of cleanliness of the Bulgarian Black Sea dunes according to the Clean Dune Index for macrolitter (size > 2.5 cm) pollution.

Dirty dunes at Strandzha Coast

The southernmost coast of Bulgaria is characterised by small settlements and villages surrounded by areas intended for recreational activities/camping. In summer, many tourists visit the area extending from Primorsko to Silistar, significantly reflecting the local ecosystem. Most dune systems were classified as "dirty" or "moderate" according to CDI values (Fig. 9; Appendix 1). The "dirty" dunes included assessment areas (29) Primorsko, (30) Atliman, (31) Dyavolska Mouth, (32) Koral, (33) Oazis, (34) Arapya, (35) Nestinarka, (36) Ahtopol and (37) Veleka Mouth. As "Moderate" polluted dunes were categorised: (28) Primorsko, (34) Arapya, (35) Nestinarka, (36) Ahtopol, (38) Butamyata and (40) Silistar. Their CDI values ranged between 7 and 19. Many assessment areas experienced significant human-induced pressure on dune systems, which were often close to commercial establishments such as beach bars and pubs. Plastic litter included items such as bottles, cigarette butts, and filters.

Ropotamo and Lipite - the cleanest dunes along the Bulgarian Coast

The study sites were deliberately chosen to include dune systems that were hard to reach, isolated from recreational activities, with limited tourist presence and a minimal anthropogenic impact on the beach. Based on the established criteria,

two dune systems, (27) Ropotamo and (39) Lipite, were chosen. As expected, after a 5-year observation period, the assessment areas were categorised as "very clean". In fact, these assessment areas exhibited the highest level of cleanliness among the study dune systems along the Bulgarian coast. The study determined that both assessment areas showed low abundance and density of litter, resulting in the lowest values of CDIav, Ropotamo, 18–22: 0.95 and CDIav, Lipite, 18–22: 1.20. Plastic litter, comprising items such as cigarette butts, bottles and fishing equipment, was prevalent on their territory. Despite the discovery of camping remnants during the field surveys, these dune systems remained relatively unaffected by human intervention. Due to their "pristine" eco-geomorphological settings, their exceptional cleanliness has earned them recognition as a reference for "very clean" coastal dunes on the Bulgarian Black Sea coast (Fig. 9; Appendix 1).

COVID-19 pandemic impact on dune cleanliness

The impact of the COVID-19 pandemic on plastic pollution in coastal and marine environments has been a subject of study in various parts of the world. For example, in neighbouring Greece, Kouvara et al. (2022) examined the impact of the ended COVID-19 pandemic on plastic pollution in the coastal/marine environment. The presence of personal protective equipment (PPE) such as face masks, gloves, and wet wipes significantly increased during the pandemic, contributing to plastic pollution. Face masks constituted the majority of PPE items found in the marine environment. COVID-19-related items accounted for a small percentage of the total litter, while wet wipes showed higher densities compared to the pre-pandemic period. Similar results of the negative impact of the COVID-19 pandemic on coastal environments have been documented in a wide range of studies worldwide (e.g., Okuku et al. 2021; Ormaza-Gonzaìlez et al. 2021; Hayati et al. 2022; Segal et al. 2022), especially the role of PPE associated with the epidemic (Akhbarizadeh et al. 2021; Benson et al. 2021; Chowdhury et al. 2021; De-la-Torre and Aragaw 2021; De-la-Torre et al. 2021; Haddad et al. 2021; Sajorne et al. 2022). From another point of view, Souza Filho et al. (2023) reported a decreasing abundance of beach litter. During the COVID-19 pandemic, beach closures and reduced public traffic led to a significant reduction of up to 83% in litter on the surveyed beaches, mostly related to recreational activities. But what was the situation during the COVID-19 epidemic on the Bulgarian beaches?

First, the 5-year timeline for monitoring dune litter remained unaffected by the COVID-19 pandemic. Bulgaria introduced a short lockdown in early March 2020, which coincided with the winter season and the beginning of spring when vacationers and campers were not expected due to low temperatures.

Second, in an effort to regulate international travel, Europe imposed restrictions during the summer seasons of 2020 and 2021. Consequently, the dunes in Bulgaria indirectly experienced the impact of the pandemic. The imposition of travel restrictions resulted in an immediate increase in domestic tourist activity on Bulgarian beaches. As a result, there was a notable 39% increase in litter abundance and a corresponding 41% rise in litter density (Figs 5, 10B). The final map of the Clean Dune Index (CDI) clearly outlines a significant jump in the amount of macrolitter, particularly single-use plastic packaging, plastic bottles, and discarded face masks. The index values revealed an increase in 38 out of the 40 areas of litter monitoring (Fig. 9B). In addition to the findings

mentioned earlier, it is worth noting that the period 2020–2022 presented a new challenge for dune ecosystems: the availability of face masks. With the advent of the COVID-19 pandemic, face masks became an essential protective measure, but unfortunately, their improper disposal resulted in an increased accumulation of litter in the dune vegetation (Fig. 11). This observation shed light on the weaknesses in waste management infrastructures and the need for improved systems to deal with the disposal of these pandemic-related items.

Conclusions

This research article presents various aspects, trends and results of mid-term 5-year monitoring of macrolitter on the Bulgarian Black Sea dunes. The 2018–2022 monitoring assessed macrolitter (size > 2.5 cm) abundance, density, composition, and sources on dunes within 40 assessment areas. According to the Master List of Categories of Litter Items in the Guidance on Monitoring of Marine Litter in European Seas (Galgani et al. 2013a), “Artificial polymer materials” accounted for 83.4% of MLD during the five-year monitoring, followed by “Paper/Cardboard” (6.2%), “Glass/ceramics” (2.8%), “Metal” (2.8%), “Processed/worked wood” (1.83%), “Rubber” (1.29%), and “Cloth/Textile” (1.17%). The COVID-19 pandemic indirectly affected Bulgarian dunes’ cleanliness by increasing domestic tourist pressure due to foreign travel restrictions. MLD abundance increased by 39%, peaking in 2021. The average density was assessed as Dav,18–22: 0.54 ± 0.35 items/m^2 - “a lot of waste in the dune area” - with a maximum of Dav,21: 0.62 in summer 2021.

The spatial distribution of macrolitter on dunes is a complicated combination of anthropogenic impact and wind processes affecting the various eco-geomorphological elements of the beach-dune system. Only 16% of items were retained by embryonic dunes (Dav,Embryo,18–22: 0.23 items/m^2). Foredunes had the most litter (28% of total items; Dav,Foredunes,18–22: 0.80 items/m^2). In larger areas, backdunes had 55% litter (Dav,Backdunes,18–22: 0.58 items/m^2). The Density Litter Maps showed that dune vegetation trapped 40% more macrolitter than sand forms without dune plants.

The Clean Dune Index was developed to assess the Bulgarian Black Sea coast dune systems’ cleanliness. Dune cleanliness along the Bulgarian coast was categorised as “moderate” by aggregated CDI data for assessment units (CDIav,18–22: 10.89). In 2018–2022, the dunes near the most popular resorts were classified as “extremely dirty”: (24) Kavatsite: 27.22, (17) Nessebar – South: 25.01, (6) Bolata: 24.69, (8) Asparuhovo (Varna): 24.33, and (16) Slanchev bryag: 24.09. The lowest CDI was for the Ropotamo and Lipite dune systems. Ropotamo 0.95 and Lipite 1.2 were “very clean”.

The manual screening procedure on the UAS orthophotos identified 93.1% of litter items initially identified by a visual survey. This recognition worked on 87% of registered litter items. UAS data is invaluable for litter location, but classifying it requires an orthophotomosaic with GSD between 0.3–0.5 cm/px. Due to the sensitive coastal dune habitats, we are obligated to continue to conduct our research using remotely non-destructive drone-based technology with minimal anthropogenic impact, following a trend away from minimizing manual sampling, which inevitably has a negative impact on dune habitats (Bekova 2023; Bekova and Prodanov 2023).

Figure 11. Example of macrolitter on dunes in assessment areas along the Bulgarian Coast.

The research on macrolitter pollution along Bulgarian dunes shows that poor management, tourist non-eco culture, and lack of clean-up activities after every summer season have resulted in a high number of dirty and extremely dirty dunes (35% of monitored dune systems).

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

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No ethical statement was reported.

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Data availability

All of the data that support the findings of this study are available in the main text.

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Appendix 1

Table A1. Monitoring data of abundance, densities, and Clean Dune Index in 2018-2022 at Bulgarian Black Sea coastal dunes.

Area of litter monitoring	Area	2018			2019			2020			2021			2022			Average (2018-2022)	
Beach-dune system	m^2	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	Density	CDI_{av}
1 Durankulak - North	7 320	1 655	0.23	4.52	1 782	0.24	4.87	2 212	0.30	6.04	2 416	0.33	6.60	3 197	0.44	8.73	0.31	8.73
2 Durankulak - South	7 536	1 695	0.22	4.50	1 826	0.24	4.85	2 267	0.30	6.02	2 635	0.35	6.99	2 967	0.39	7.87	0.30	7.87
3 Krapets - North	8 399	2 693	0.32	6.41	3 294	0.39	7.84	4 429	0.53	10.55	4 832	0.58	11.51	3 115	0.37	7.42	0.44	7.42
4 Shabla - North	6 827	1 882	0.28	5.51	2 027	0.30	5.94	2 516	0.37	7.37	2 390	0.35	7.00	2 178	0.32	6.38	0.32	6.38
5 Shabla - South	5 546	1 244	0.22	4.49	1 340	0.24	4.83	1 917	0.35	6.91	1 971	0.36	7.11	1 871	0.34	6.75	0.30	6.75
6 Bolata	1 175	1 082	0.92	18.42	1 166	0.99	19.84	1 562	1.33	26.59	1 746	1.49	29.72	1 697	1.44	28.89	1.23	28.89
7 Kranevo - Albena	6 114	2 170	0.35	7.10	2 337	0.38	7.64	3 142	0.51	10.28	2 755	0.45	9.01	2 511	0.41	8.21	0.42	8.21
8 Asparuhovo (Varna)	5 604	4 812	0.86	17.17	5 186	0.93	18.51	8 723	1.56	31.13	7 186	1.28	25.64	8 193	1.46	29.24	1.22	29.24
9 Pasha Dere	7 435	881	0.12	2.37	948	0.13	2.55	1 177	0.16	3.17	1 118	0.15	3.01	1 019	0.14	2.74	0.14	2.74
10 Kamchiya (Mouth)	6 708	1 015	0.15	3.03	1 093	0.16	3.26	1 357	0.20	4.05	1 289	0.19	3.84	1 175	0.18	3.50	0.18	3.50
11 Kamchiya - South (Novo Oryahovo Beach)	4 894	716	0.15	2.93	819	0.17	3.35	1 424	0.29	5.82	1 411	0.29	5.77	1 641	0.34	6.71	0.25	6.71
12 Shkorpilovtsi	5 591	1 764	0.32	6.31	1 900	0.34	6.80	2 358	0.42	8.44	2 240	0.40	8.01	2 041	0.37	7.30	0.37	7.30
13 Shkorpilovtsi - South	4 826	1 533	0.32	6.36	1 651	0.34	6.84	2 050	0.42	8.50	1 947	0.40	8.07	1 775	0.37	7.35	0.37	7.35
14 Kara Dere - North (Byala)	5 368	1 130	0.21	4.21	1 217	0.23	4.53	2 110	0.39	7.86	1 716	0.32	6.39	1 923	0.36	7.16	0.30	7.16
15 Kara Dere - South (Byala)	5 785	882	0.15	3.05	950	0.16	3.28	1 179	0.20	4.08	1 120	0.19	3.87	1 021	0.18	3.53	0.18	3.53
16 Slanchev bryag	7 753	7 223	0.93	18.63	7 779	1.00	20.07	9 656	1.25	24.91	11 813	1.52	30.47	10 231	1.32	26.39	1.20	26.39
17 Nessebar - South	7 987	8 113	1.02	20.32	8 738	1.09	21.88	10 846	1.36	27.16	10 301	1.29	25.79	11 941	1.50	29.90	1.25	29.90
18 Aheloy	5 612	2 092	0.37	7.46	2 253	0.40	8.03	2 797	0.50	9.97	3 115	0.56	11.10	2 422	0.43	8.63	0.45	8.63
19 Pomorie Sand Spit	5 114	813	0.16	3.18	875	0.17	3.42	1 086	0.21	4.25	1 482	0.29	5.80	1 713	0.33	6.70	0.23	6.70
20 Burgas Port Wall	5 087	4 492	0.88	17.66	4 838	0.95	19.02	6 005	1.18	23.61	5 704	1.12	22.42	5 199	1.02	20.44	1.03	20.44
21 Vromos	8 125	2 223	0.27	5.47	2 394	0.29	5.89	2 972	0.37	7.31	4 118	0.51	10.14	2 573	0.32	6.33	0.35	6.33
22 Campsite Gradina	9 451	5 639	0.60	11.93	6 073	0.64	12.85	7 538	0.80	15.95	8 176	0.87	17.30	6 526	0.69	13.81	0.72	13.81
23 Harmanite	5 138	3 339	0.65	13.00	3 596	0.70	14.00	4 464	0.87	17.38	4 240	0.83	16.50	3 865	0.75	15.04	0.76	15.04
24 Kavatsite	5 137	5 113	1.00	19.91	5 812	1.13	22.63	7 789	1.52	30.33	8 136	1.58	31.68	8 111	1.58	31.58	1.36	31.58

Area of litter monitoring	Area	2018			2019			2020			2021			2022			Average (2018-2022)	
Beach-dune system	m^2	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	$Items_{av}$	D_{av}	CDI_{av}	Density	CDI_{av}
25 Alepu	5 412	1 773	0.33	6.55	1 909	0.35	7.06	2 370	0.44	8.76	2 681	0.50	9.91	2 052	0.38	7.58	0.40	7.58
26 Arkutino	5 088	1 193	0.23	4.69	1 285	0.25	5.05	1 595	0.31	6.27	1 515	0.30	5.95	1 380	0.27	5.43	0.27	5.43
27 Ropotamo	5 144	156	0.03	0.61	168	0.03	0.65	209	0.04	0.81	502	0.10	1.95	181	0.04	0.70	0.05	0.70
28 Primorsko (Stamopolu)	13 415	6 407	0.48	9.55	6 900	0.51	10.29	8 809	0.66	13.13	8 135	0.61	12.13	7 415	0.55	11.05	0.56	11.05
29 Primorsko (Mladost MMC)	5 759	3 170	0.55	11.01	3 414	0.59	11.86	4 238	0.74	14.72	4 025	0.70	13.98	3 669	0.64	12.74	0.64	12.74
30 Atliman	5 009	2 655	0.53	10.60	2 859	0.57	11.42	3 549	0.71	14.17	3 371	0.67	13.46	3 072	0.61	12.27	0.62	12.27
31 Dyavolska Mouth	6 296	4 278	0.68	13.59	4 607	0.73	14.63	5 719	0.91	18.17	5 432	0.86	17.25	4 951	0.79	15.73	0.79	15.73
32 Koral	5 120	2 791	0.55	10.90	3 006	0.59	11.74	3 731	0.73	14.58	3 544	0.69	13.84	3 230	0.63	12.62	0.64	12.62
33 Oazis	5 239	4 309	0.82	16.45	4 641	0.89	17.72	5 761	1.10	21.99	5 472	1.04	20.89	4 987	0.95	19.04	0.96	19.04
34 Arapya	6 560	3 297	0.50	10.05	2 936	0.45	8.95	3 645	0.56	11.11	3 461	0.53	10.55	3 155	0.48	9.62	0.50	9.62
35 Nestinarka	4 438	2 045	0.46	9.22	2 203	0.50	9.93	2 734	0.62	12.32	2 597	0.59	11.70	2 367	0.53	10.67	0.54	10.67
36 Ahtopol	5 635	1 543	0.27	5.48	1 662	0.29	5.90	2 540	0.45	9.02	2 616	0.46	9.28	1 786	0.32	6.34	0.36	6.34
37 Veleka Mouth	7 064	4 314	0.61	12.22	4 647	0.66	13.16	5 768	0.82	16.33	5 478	0.78	15.51	4 993	0.71	14.14	0.71	14.14
38 Butamyata	5 089	1 885	0.37	7.41	2 030	0.40	7.98	2 520	0.50	9.90	2 393	0.47	9.41	2 182	0.43	8.57	0.43	8.57
39 Lipite	3 441	176	0.05	1.02	190	0.06	1.10	236	0.07	1.37	224	0.07	1.30	204	0.06	1.19	0.06	1.19
40 Silistar	5 118	2 457	0.48	9.60	2 646	0.52	10.34	3 285	0.64	12.84	3 120	0.61	12.19	2 844	0.56	11.11	0.56	11.11
Mean values:		2 666	0.44	8.82	2 875	0.48	9.51	3 707	0.62	12.33	3 710	0.62	12.33	3 434	0.57	11.49	0.54	11.49
Minimum:		156	0.03	0.61	168	0.03	0.65	209	0.04	0.81	224	0.07	1.30	181	0.04	0.70	0.05	0.70
Maximum:		8 113	1.02	20.32	8 738	1.13	22.63	10 846	1.56	31.13	11 813	1.58	31.68	11 941	1.58	31.58	1.36	31.58
Standard deviation:		1 913	0.28	5.52	2 068	0.30	5.99	2 657	0.40	7.93	2 679	0.40	7.91	2 641	0.40	8.03	0.35	8.03
Standard error:		48	0.01	0.14	52	0.01	0.15	66	0.01	0.20	67	0.01	0.20	66	0.01	0.20	0.01	0.20

Appendix 2

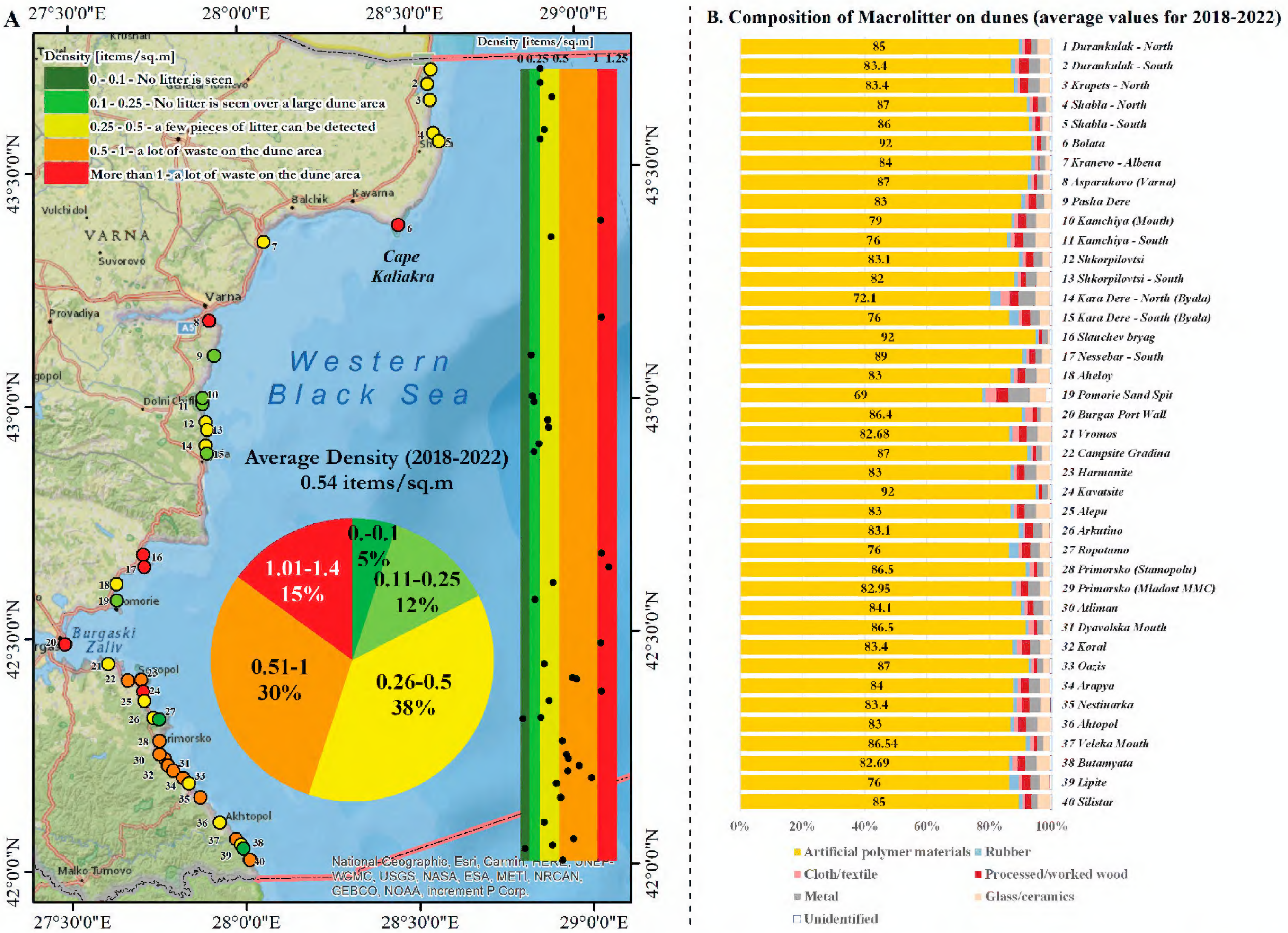

Figure A1. **A** Map of the average densities of MLD along the BBSC **B** the average values of litter composition on the ALMs in 2018–2022 (see Appendix 1).

Appendix 3

Table A2. Composition of litter on dunes along the Bulgarian Black Sea Coast in 2018–2022.

Area of litter monitoring	Artificial polymer materials	Rubber	Cloth/ Textile	Paper/ Cardboard	Processed/ Worked wood	Metal	Glass/ Ceramics	Unidentified
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
1 Durankulak - North	85.0	1.1	0.8	4.9	1.9	1.9	3.8	0.6
2 Durankulak - South	83.4	1.4	1.0	4.2	2.9	3.6	3.0	0.6
3 Krapets - North	83.4	1.1	1.0	5.1	2.3	3.6	3.0	0.6
4 Shabla - North	87.0	0.9	1.0	5.4	1.5	2.6	1.0	0.6
5 Shabla - South	86.0	1.1	1.0	7.1	1.2	1.0	2.0	0.6
6 Bolata	92.0	0.8	1.0	1.6	1.3	1.6	1.1	0.6
7 Kranevo - Albena	84.0	1.2	1.0	10.0	0.3	1.6	1.4	0.5
8 Asparuhovo (Varna)	87.0	1.2	1.0	5.7	0.8	1.8	2.0	0.6
9 Pasha Dere	83.0	1.2	1.0	8.0	2.3	2.3	2.0	0.2
10 Kamchiya (Mouth)	79.0	0.9	1.0	9.3	2.3	2.9	4.0	0.6
11 Kamchiya - South (Novo Oryahovo Beach)	76.0	1.2	1.0	11.3	2.3	3.6	4.0	0.6

Area of litter monitoring	Artificial polymer materials	Rubber	Cloth/ Textile	Paper/ Cardboard	Processed/ Worked wood	Metal	Glass/ Ceramics	Unidentified
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
12 Shkorpilovtsi	83.1	1.1	1.0	7.1	2.3	2.8	2.0	0.6
13 Shkorpilovtsi - South	82.0	0.9	1.0	6.9	1.4	3.3	3.9	0.6
14 Kara Dere - North (Byala)	72.1	3.1	2.8	10.0	2.3	5.1	4.0	0.6
15 Kara Dere - South (Byala)	76.0	2.7	1.0	12.0	2.3	2.6	2.8	0.6
16 Slanchev bryag	92.0	0.8	0.3	3.0	0.8	1.9	0.6	0.6
17 Nessebar - South	89.0	1.4	1.0	1.7	1.8	2.1	2.6	0.5
18 Aheloy	83.0	1.2	1.0	4.3	2.3	3.6	4.0	0.6
19 Pomorie Sand Spit	69.0	1.0	3.1	11.2	3.3	6.1	4.7	1.6
20 Burgas Port Wall	86.4	1.1	2.3	4.3	1.3	1.3	3.1	0.2
21 Vromos	82.7	1.1	1.8	4.3	2.3	3.6	4.0	0.2
22 Campsite Gradina	87.0	1.3	0.6	5.6	0.8	1.8	2.3	0.6
23 Harmanite	83.0	1.2	0.9	4.3	2.3	3.6	4.1	0.6
24 Kavatsite	92.0	0.8	0.3	3.0	0.8	1.9	0.6	0.6
25 Alepu	83.0	1.2	0.8	4.3	2.3	3.6	4.2	0.6
26 Arkutino	83.1	1.4	0.6	7.0	2.3	2.8	2.2	0.6
27 Ropotamo	76.0	2.7	1.1	11.9	2.3	2.6	2.8	0.6
28 Primorsko (Stamopolu)	86.5	1.2	1.5	5.6	0.8	1.8	2.0	0.6
29 Primorsko (Mladost MMC)	83.0	1.4	1.3	4.9	2.3	3.6	3.0	0.6
30 Atliman	84.1	1.1	1.0	6.6	1.8	2.8	2.0	0.6
31 Dyavolska Mouth	86.5	0.8	1.9	5.6	0.8	1.8	2.0	0.6
32 Koral	83.4	1.3	1.7	4.6	2.3	3.3	3.0	0.4
33 Oazis	87.0	1.0	0.9	5.9	0.8	1.8	2.0	0.6
34 Arapya	84.0	1.2	1.0	4.3	2.3	3.6	3.0	0.6
35 Nestinarka	83.4	1.1	1.4	4.9	2.3	3.6	3.0	0.3
36 Ahtopol	83.0	1.2	1.2	4.3	2.3	3.6	4.0	0.4
37 Veleka Mouth	86.5	1.4	1.3	5.6	0.8	1.8	2.0	0.6
38 Butamyata	82.7	1.1	1.4	4.3	2.3	3.6	4.0	0.6
39 Lipite	76.0	2.7	1.0	12.0	2.3	2.6	2.8	0.6
40 Silistar	85.0	1.2	0.8	4.9	1.9	1.9	3.8	0.5
Average, [%]	**83.4**	**1.3**	**1.2**	**6.2**	**1.8**	**2.8**	**2.8**	**0.6**

Appendix 4

Table A3. Comparison of average litter density on dunes and beaches (Bekova and Prodanov 2023) in 2018–2022.

Year	2018		2019		2020		2021		2022	
D-*dunes*; B-*beaches*	D	B	D	B	D	B	D	B	D	B
Areas of Litter Monitoring (Dune system)	Litter Density, [items/m^2]									
1 Durankulak - North	**0.23**	0.11	**0.24**	0.14	**0.30**	0.32	**0.33**	0.41	**0.44**	0.17
2 Durankulak - South	**0.22**	0.11	**0.24**	0.18	**0.30**	0.33	**0.35**	0.39	**0.39**	0.09
3 Krapets - North	**0.32**	0.12	**0.39**	0.18	**0.53**	0.35	**0.58**	0.41	**0.37**	0.11
4 Shabla - North	**0.28**	0.10	**0.30**	0.15	**0.37**	0.29	**0.35**	0.34	**0.32**	0.13
5 Shabla - South	**0.22**	0.12	**0.24**	0.19	**0.35**	0.36	**0.36**	0.44	**0.34**	0.10

Year	**2018**		**2019**		**2020**		**2021**		**2022**	
D-*dunes*; B-*beaches*	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**	**D**	**B**
Areas of Litter Monitoring (Dune system)	**Litter Density, [items/m²]**									
6 Bolata	**0.92**	0.51	**0.99**	0.82	**1.33**	1.54	**1.49**	1.85	**1.44**	0.41
7 Kranevo - Albena	**0.35**	0.18	**0.38**	0.28	**0.51**	0.53	**0.45**	0.63	**0.41**	0.32
8 Asparuhovo (Varna)	**0.86**	0.49	**0.93**	0.78	**1.56**	1.10	**1.28**	1.22	**1.46**	0.26
9 Pasha Dere	**0.12**	0.06	**0.13**	0.09	**0.16**	0.17	**0.15**	0.21	**0.14**	0.05
10 Kamchiya (Mouth)	**0.15**	0.07	**0.16**	0.12	**0.20**	0.22	**0.19**	0.27	**0.18**	0.06
11 Kamchiya - South	**0.15**	0.10	**0.17**	0.16	**0.29**	0.31	**0.29**	0.37	**0.34**	0.08
12 Shkorpilovtsi	**0.32**	0.15	**0.34**	0.25	**0.42**	0.46	**0.40**	0.55	**0.37**	0.10
13 Shkorpilovtsi South	**0.32**	0.15	**0.34**	0.25	**0.42**	0.46	**0.40**	0.56	**0.37**	0.07
14 Kara Dere - North (Byala)	**0.21**	0.10	**0.23**	0.16	**0.39**	0.31	**0.32**	0.37	**0.36**	0.18
15 Kara Dere - South (Byala)	**0.15**	0.07	**0.16**	0.12	**0.20**	0.22	**0.19**	0.27	**0.18**	0.13
16 Slanchev bryag	**0.93**	0.48	**1.00**	0.77	**1.25**	1.45	**1.52**	1.55	**1.32**	0.82
17 Nessebar - South	**1.02**	0.49	**1.09**	0.79	**1.36**	1.48	**1.29**	1.44	**1.50**	0.86
18 Aheloy	**0.37**	0.16	**0.40**	0.25	**0.50**	0.47	**0.56**	0.56	**0.43**	0.27
19 Pomorie Sand Spit	**0.16**	0.10	**0.17**	0.16	**0.21**	0.29	**0.29**	0.35	**0.33**	0.17
20 Burgas Port Wall	**0.88**	0.43	**0.95**	0.69	**1.18**	1.08	**1.12**	1.31	**1.02**	0.76
21 Vromos	**0.27**	0.15	**0.29**	0.23	**0.37**	0.44	**0.51**	0.53	**0.32**	0.26
22 Campsite Gradina	**0.60**	0.30	**0.64**	0.48	**0.80**	0.90	**0.87**	1.08	**0.69**	0.53
23 Harmanite	**0.65**	0.32	**0.70**	0.51	**0.87**	0.95	**0.83**	1.14	**0.75**	0.56
24 Kavatsite	**1.00**	0.57	**1.13**	0.90	**1.52**	1.34	**1.58**	1.49	**1.58**	0.75
25 Alepu	**0.33**	0.17	**0.35**	0.27	**0.44**	0.50	**0.50**	0.60	**0.38**	0.25
26 Arkutino	**0.23**	0.09	**0.25**	0.14	**0.31**	0.27	**0.30**	0.32	**0.27**	0.16
27 Ropotamo	**0.03**	0.02	**0.03**	0.03	**0.04**	0.06	**0.10**	0.07	**0.04**	0.03
28 Primorsko (Stamopolu)	**0.48**	0.23	**0.51**	0.37	**0.66**	0.70	**0.61**	0.84	**0.55**	0.37
29 Primorsko (Mladost MMC)	**0.55**	0.27	**0.59**	0.43	**0.74**	0.80	**0.70**	0.96	**0.64**	0.36
30 Atliman	**0.53**	0.26	**0.57**	0.41	**0.71**	0.77	**0.67**	0.93	**0.61**	0.34
31 Dyavolska Mouth	**0.68**	0.29	**0.73**	0.46	**0.91**	0.87	**0.86**	1.04	**0.79**	0.51
32 Koral	**0.55**	0.27	**0.59**	0.42	**0.73**	0.80	**0.69**	0.96	**0.63**	0.35
33 Oazis	**0.82**	0.26	**0.89**	0.56	**1.10**	1.05	**1.04**	1.11	**0.95**	0.55
34 Arapya	**0.50**	0.21	**0.45**	0.34	**0.56**	0.63	**0.53**	0.75	**0.48**	0.27
35 Nestinarka	**0.46**	0.22	**0.50**	0.36	**0.62**	0.67	**0.59**	0.81	**0.53**	0.38
36 Ahtopol	**0.27**	0.15	**0.29**	0.24	**0.45**	0.45	**0.46**	0.54	**0.32**	0.26
37 Veleka Mouth	**0.61**	0.30	**0.66**	0.48	**0.82**	0.89	**0.78**	1.07	**0.71**	0.52
38 Butamyata	**0.37**	0.18	**0.40**	0.29	**0.50**	0.54	**0.47**	0.65	**0.43**	0.32
39 Lipite	**0.05**	0.02	**0.06**	0.04	**0.07**	0.07	**0.07**	0.09	**0.06**	0.04
40 Silistar	**0.48**	0.21	**0.52**	0.33	**0.64**	0.62	**0.61**	0.74	**0.56**	0.36
Average annual density, **[items/m²]**	**0.44**	**0.21**	**0.48**	**0.35**	**0.61**	**0.63**	**0.64**	**0.73**	**0.53**	**0.31**
Total Average density, Time period 2018-2022, **[items/m²]**	Dunes – **0.54**					Beaches – **0.44**				
Total Average Percentage difference, **[%]**	**21.12% ~ 20%**									